EVALUATION OF NATURAL MATERIALS AS LONG-TERM BARRIERS FOR URANIUM MINE TAILINGS - PHASE I

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MICROMEDIA

"Evaluation of Natural Barriers as
Long-Term Barriers for Uranium Mine Tailings"

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EXECUTIVE SUMMARY

INTRODUCTION

The National Uranium Tailings Program commissioned a study on the use of natural materials as long-term barriers for uranium mine tailings. Clifton Associates Ltd., in association with Gartner Lee Associates Limited, Melis Consulting Engineers Ltd. and Steffen Robertson & Kirsten (B.C.) Inc. were retained by Supply and Services Canada to conduct Phase I of this study. This study identifies the current, and potential properties in Canada; assesses the leachate characteristics that might be expected from mill tailings produced at each deposit; inventories the natural materials that are available for barrier construction; identifies the materials that are presently used for barrier construction; assesses the chemical and physical stability of the natural materials in the presence of uranium tailings leachates; and, recommends a second phase program to gather further information.

CURRENT AND POTENTIAL URANIUM PRODUCERS AND ORE TYPES

The current and potential mines were identified. The current producers included the Denison, Quirke, Panel and Stanleigh Mines in the Elliot Lake area; and, the Cluff Lake, Key Lake and Rabbit Lake Mines of Northern Saskatchewan. The deposits judged to have a reasonable potential to become commercial sometime in the future include Cigar Lake, Dawn Lake, McClean Lake and the Midwest Lake ore bodies of Northern Saskatchewan. Other possible areas include the Lone Gull deposits at Baker Lake, Northwest Territories; the Blizzard property in British Columbia; the Saint Kitts/Michelin deposits of Labrador; and, other exploration sites in the Athabasca Basin.

The ore from the current producers can be classified into three general categories. These include the Elliot Lake type, a sulphide bearing ore of relatively low grade found at the four operating mines in the Elliot Lake area; the Key Lake type, a nickel/arsenic sulphide ore found at Key Lake and Collins Bay "B" Zone; and, the Rabbit Lake type, a relatively clean, low sulphide ore found at the Rabbit Lake Mine and Cluff Lake Phase II.

TAILINGS WATER CHARACTERISTICS

The initial ore composition is an important factor in the trace element concentrations in the pore water, and in the quality of pore water at later stages in its geochemical evolution. However, the major dissolved components in the tailings pore water appear to be much more dependent upon the process reagents than on the initial ore composition. All of the mines considered produce a calcium sulphate saturated, moderate to high pH pore fluid. The pore fluid goes through a geochemical evolution, changing in composition with time. There are four stages of evolution of the geochemistry of the pore water:

- A process controlled phase governed by reagents added during ore processing and tailings neutralization. This phase lasts for the operational life of the impoundment.

- The sulphide oxidation stage, lasting to about year 200, during which sulphide minerals are oxidized producing hydrogen ions, reducing pH and dissolving precipitates. The pH during this phase could drop as low as two.

- The re-solution phase, which is dominated by low pH and high sulphate concentrations if sulphide minerals are present in the ore. The time of re-solution will depend on infiltration rate and percentage of gypsum but, for normal infiltration, this stage would take place from approximately year 200 to year 600 after decommissioning. Aluminum will precipitate, keeping the pH low. The end point of this state is reached when all the gypsum has been dissolved. If no sulphide minerals are present in the ore, this stage will still take place, except the pH will drop from 10 to about 7 or less.

- The infiltration stage is the last stage of pore water evolution. During this stage, which will continue into geological time, all geochemical reactions and re-solution processes have been completed. Some alteration of clay minerals and silicates will continue, but the pH and composition will approximately reflect meteoric water in the area.

The net result of this proposed model is a "generic" composition for tailings seepage. The presence of sulphides in the ore is important only in that it affects the way in which the pore water composition evolves. The interaction of the seepage and soil barriers can also be evaluated in similar stages.

AVAILABLE MATERIALS

Existing data on surficial geology and material tests in the Cluff Lake, Key Lake, Rabbit Lake and Elliot Lake areas were examined to determine what types of materials might be available for construction of low permeability barriers. The northern Saskatchewan mining areas had abundant coarse grained till, sand and gravel. Fine grained sediments were virtually absent at all the sites except Rabbit Lake. There, deposits of lacustrine silt and clay were identified in Collins Bay. Peat was abundant, and the few available tests indicate that it will compress to form a low permeability barrier. The mineral soils had high strength, low compressibility and relatively high permeability.

The natural sediments in the Elliot Lake area consist of till, sand, gravel, silt and peat. The potential barrier materials include silty till, silt and peat. Test data were only available on the silty till, but these indicated it could be compacted to achieve a permeability of less than 1×10^{-8} m/sec.

CURRENT BARRIERS

The natural materials currently being used in barriers at the producing mines include compacted till at Elliot Lake and Rabbit Lake, and soil modified with commercial bentonite at Cluff Lake and Key Lake. The soil-bentonite mixtures were used both in a slurry trench cutoff and compacted cutoffs.

GEOCHEMICAL STABILITY OF BARRIERS

Hydrogeochemical solute transfer processes were evaluated, along with the effects of such processes on the physical behaviour of the barrier materials. The principal processes affecting solute transfer have previously been identified. These include dissolution reactions, replacement reactions, precipitation reactions and ion exchange. This study examines the chemical effects of the seepage on the natural barrier materials during each of the four "generic" stages in the geochemical evolution of the tailings pore water. Four natural barrier materials, till, silt, clay and peat, were considered along with a till soil modified with sodium bentonite. Little change is expected in the till barrier during the operational life, or for the first 600 years after decommissioning. If sulphides are present, deposition of gypsum in the pore spaces is predicted during the first 200 years, reducing permeability. This gypsum will dissolve in years 200 to 600 leading to slightly increased permeability. In the very long-term, slow solution of residual carbonate and some decomposition of mineral phases at pH 5 is expected to lead to slightly increased permeability. Similar results are expected for silt.

The seepage effects on clay barriers depends on the clay mineralogy. Clays comprised of sodium minerals would undergo significant ion exchange leading to shrinkage and increased permeability during the operating life. During the next 200 years, the permeability would undergo little change or increase marginally if hydrogen replacement of calcium takes place. Long-term weathering of the barrier in geologic time could be expected to increase permeability.

Peat is expected to be durable during the operating life of a pond and experience only small changes in permeability thereafter.

The greatest changes in soil-bentonite mixtures are expected during the operating life of the mine. The calcium-rich initial seepage can be expected to initiate substitution of calcium for sodium in the mineral lattice of the bentonite, causing shrinkage if the molding water content is above the plastic limit. This shrinkage would lead to increased permeability. Sodium bearing clay additives may not be successful (by themselves) in preventing calcium-rich neutralized seepage in the long-term. Some benefit will be derived, however, from gradation improvements.

ATTENUATION OF CONTAMINANTS

The soil barrier materials themselves offer attenuation of radionuclides and metals. Most of the natural soils are calcareous, and will neutralize acid seepage, reducing the mobility of these species. Surface absorption and cation exchange mechanisms will operate to varying degrees depending upon the properties of the barrier material and chemical composition of the seepage at any particular time. Soils with a higher clay and carbonate content are expected to provide greater geochemical attentuation, while peat would provide the least geochemical attenuation but probably the highest absorption potential of the materials considered.

PHYSICAL STABILITY OF BARRIERS

Permeability can increase due to physical changes as well as chemical attack. Undesirable physical changes include an increase in the void ratio, the development of cracks or fissures in the soil, and piping of soil by seepage. Important mechanisms include shrinking or swelling in high plasticity (montmorillonitic) soils; cold temperature cracking in dry compacted soils, particularly during liner construction; thaw consolidation, the process of water seeping during thawing of ice lenses in the soil; and, piping by seepage. Osmotic consolidation, the process whereby concentrated leachate can draw water from a soil compacted with fresh water and cause shrinkage, may be an important consideration in the construction of soil-bentonite cutoffs.

SOIL MODIFICATION

Soil modification has been used to reduce seepage losses at several current mines. Compaction is the most common way of reducing permeability, but soil-bentonite mixtures have also been used. Compacted soil-bentonite cutoffs are constructed using 4 to 5 percent commercial bentonite mixed with the soil and compacting it to a high density at a relatively low water content. Soil-bentonite slurry cutoffs utilize approximately the same amount of bentonite, but the slurry is placed in a very wet consistency in a trench. The local tills in northern Saskatchewan are suitable for modification with bentonite.

EXTRAPOLATION TO FUTURE MINE AREAS

An attempt was made to extrapolate this experience to potential and possible producing areas. It was estimated that most of the known uranium deposits would fall into one of the three generic categories studied in this report, and so the effects of seepage on natural barriers could likewise be estimated. The Blizzard and Saint Kitts/Michelin deposits are exceptions.

PHASE II PROPOSAL

This program was a Phase I study, based on a review of existing data only. It is apparent that there is a lack of data on actual permeabilities of materials used in the uranium mining area, and an absence of data regarding the changes in permeability with time. Similarly, there are very few data on changes in permeability due to chemical reaction in the barriers. A proposal is included for additional work to address some of these problems in a future phase of this work.

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1.0 INTRODUCTION

This report presents an examination of the state of technology in the use of natural materials as barriers for waterborne contaminants from uranium tailings in Canada. The scope of the work was to:

° Identify current and potential uranium ore mining areas in Canada and generally describe the geographical, geological and hydrological environment for each area.

° Identify locally available materials that are or could be used to construct low hydraulic conductivity barriers for waterborne contaminants from uranium mine wastes.

° Describe the chemistry of waterborne contaminants that result from current uranium ore processing technology.

° Briefly describe the processes used for soil-till modification.

° Detail the physical characteristics of low conductivity materials that are locally available in current and potential uranium mining areas.

° Detail the chemical and mineralogical characteristics of uranium tailings barrier materials for the two current uranium mining areas (Elliot Lake, Ontario and northern Saskatchewan).

° Identify mechanisms and rates of transfer of contaminants through engineered and natural barriers that are composed of natural or modified soils.

° Extend the findings on mechanisms and rates of transfer to other uranium producing areas in Canada.

- Prepare a technical proposal and cost estimate for the Phase II test program.

All of this work was completed on the basis of existing information obtained from the files of consulting engineers, government agencies and mining companies. No new or original investigations were undertaken.

The following report examines the general geography and geology of the uranium producing areas in Section 2; identifies the ore characteristics and milling processes for the various mines in Section 3; the leachate characteristics in Section 4; and then inventories conditions at specific uranium producing areas (Cluff Lake, Key Lake, Midwest Lake-Rabbit Lake and Elliot Lake) in Sections 5 to 8 inclusive. Sections 9 to 11 inclusive generically look at mechanisms and tranfer rates, including geochemical and physical stability, and soil modification procedures to improve stability and reduce transfer rates. Section 12 examines how the results may be extended to other uranium producing areas. A proposal for Phase II testing is presented in Section 13.

2.0 URANIUM PRODUCING AREAS IN CANADA

2.1 General

The location of uranium areas in Canada is identified in Figure 2-1. The areas of concern identified for this study include:

Current Producers (1985)

- Elliot Lake Area
  - Denison Mine
  - Quirke Mine
  - Panel Mine
  - Stanleigh Mine

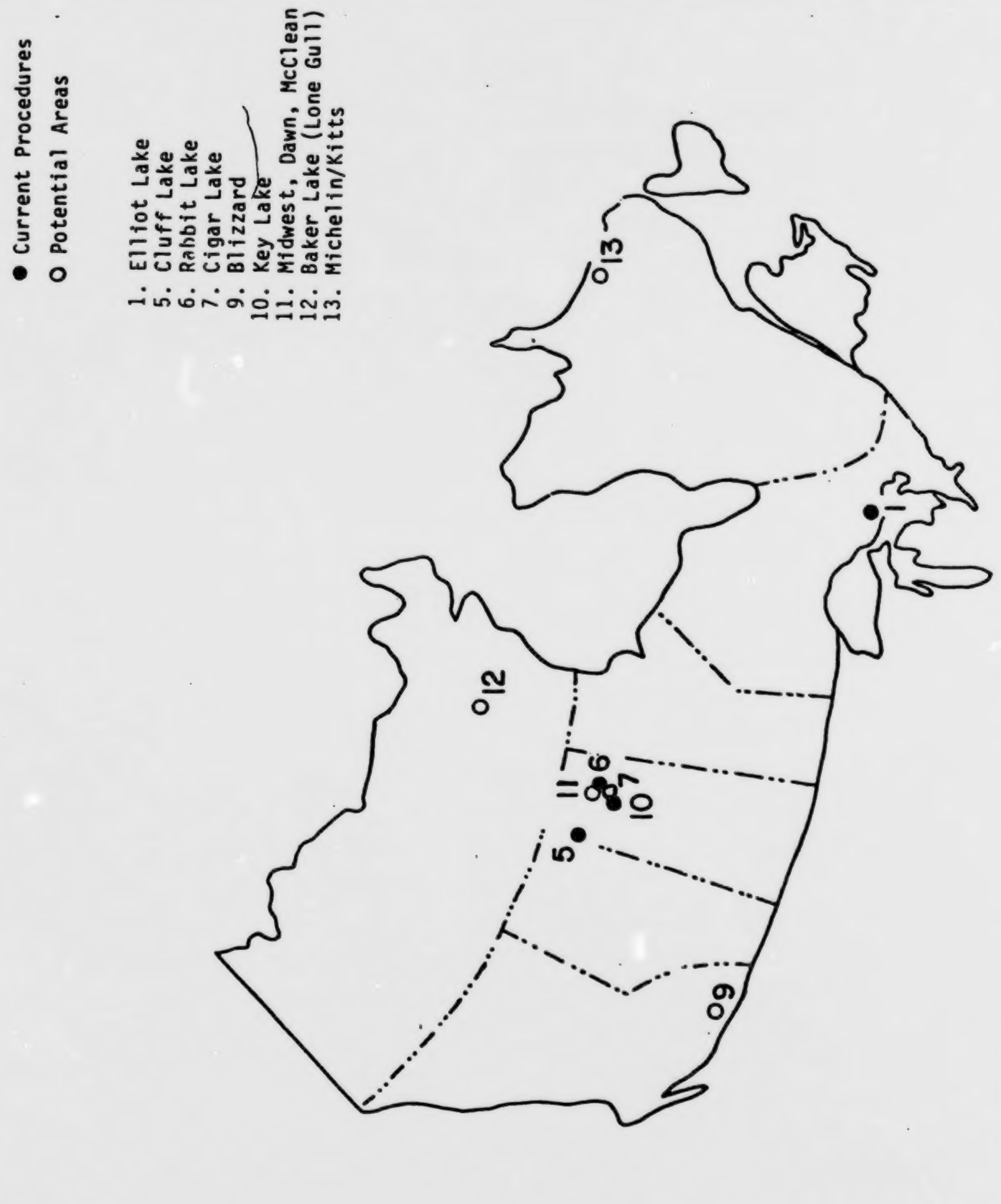
- Northern Saskatchewan
  - Cluff Lake Mine
  - Key Lake Mine
  - Rabbit Lake/Collins Bay Mine

Potential Areas

- Northern Saskatchewan
  - Collins Bay A Zone, D Zone and Eagle Point
  - Cigar Lake
  - Dawn Lake
  - McClean Lake
  - Midwest Lake

Possible Areas

- Baker Lake
  - Lone Gull Deposit



LOCATION OF URANIUM AREAS IN CANADA
(ADAPTED FROM PLANNING GROUP REPORT, SEPTEMBER 1981)

FIGURE 2-1

- Athabasca Basin
  - other exploration sites
- British Columbia
  - Blizzard property
- Labrador
  - Kitts/Michelin deposits

2.2 Current Producers (1985)

Elliot Lake Area

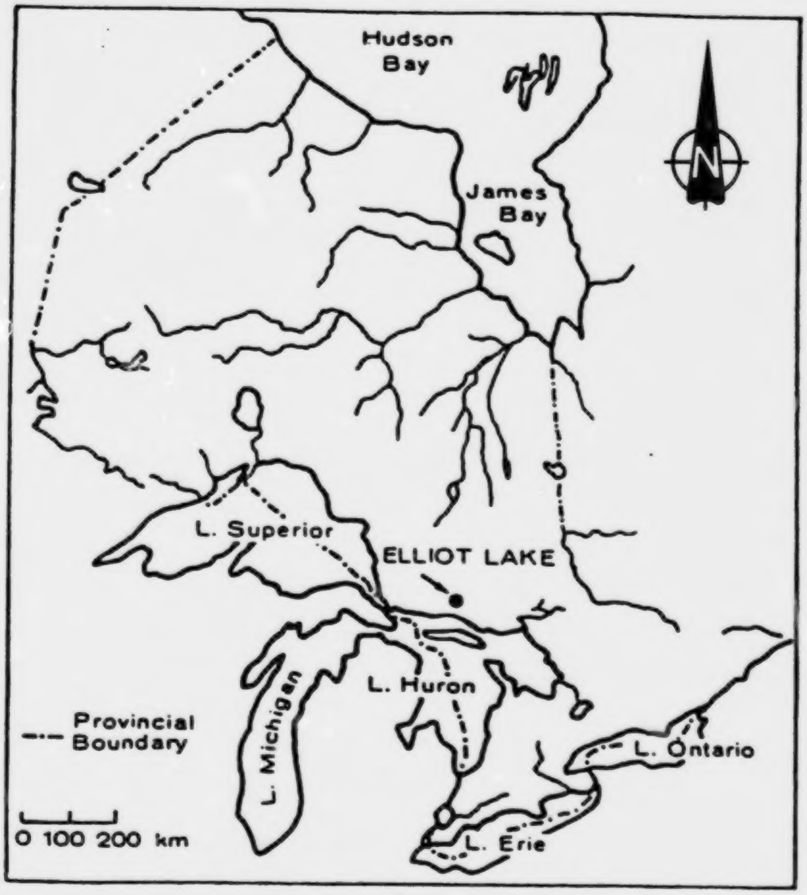
The Elliot Lake uranium mining area in northern Ontario is shown on the location map given in Figure 2-2 with a detailed map identifying the location of uranium mines in the Elliot Lake region provided in Figure 2-3. As identified above, current producers in Elliot Lake include the Denison mine operated by Denison Mines Limited; and the Quirke, Panel and Stanleigh mines operated by Rio Algom Limited.

Northern Saskatchewan

Uranium mining operations in northern Saskatchewan are located within the Athabasca Basin. They include the Cluff Lake mining operation in the Carswell structure area of northern Saskatchewan, the Key Lake mine at the southern edge of the Basin and the Rabbit Lake operation on the eastern side of the Basin. A general location map is shown in Figure 2-4.

2.3 Potential Areas

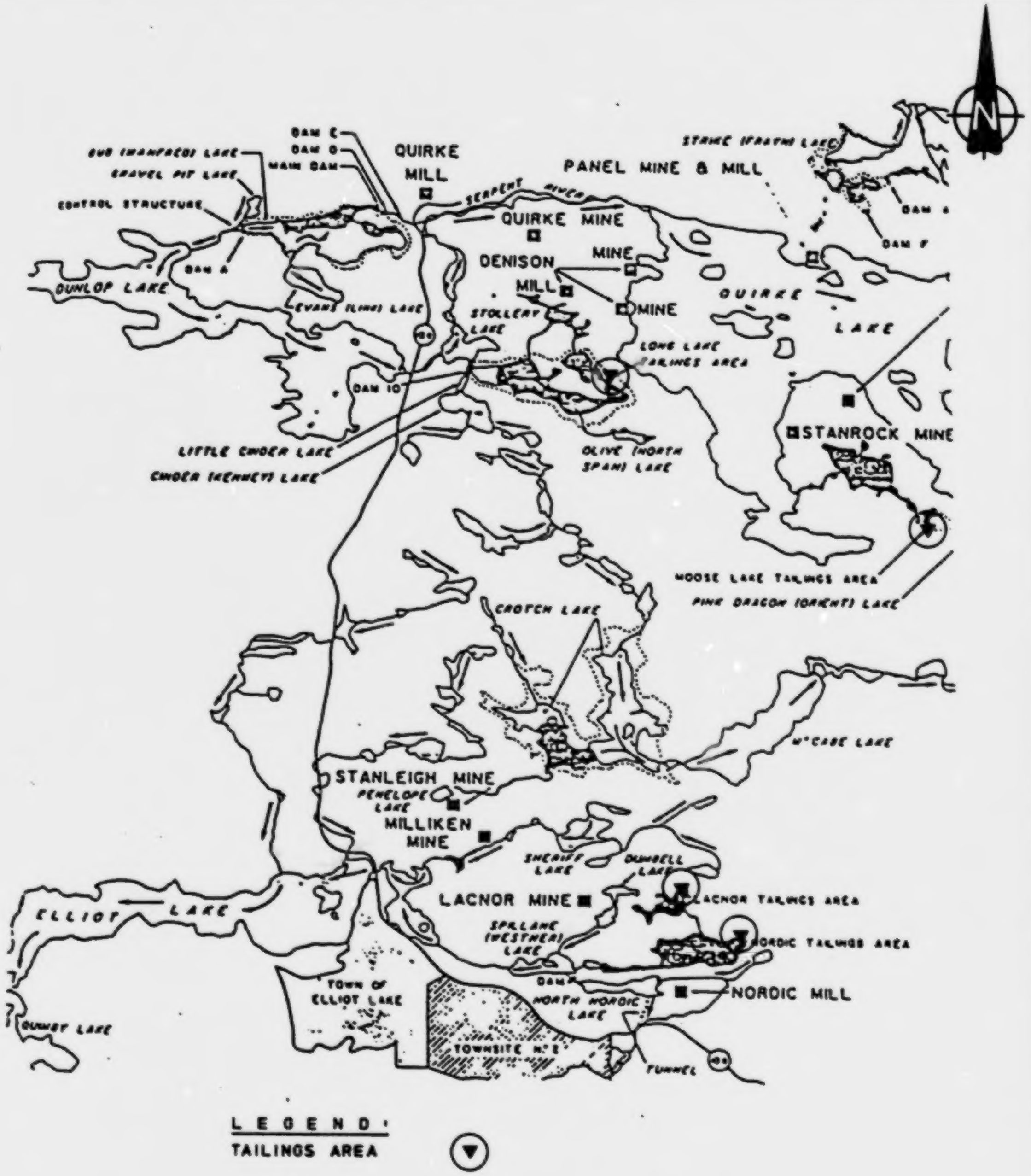
The main potential area for future uranium mines in Canada will continue to be in northern Saskatchewan. There are several deposits in this area which remain to be developed. The major deposit is the high-grade Cigar Lake Project which is located immediately south of Waterbury Lake in northern



SITE PLAN

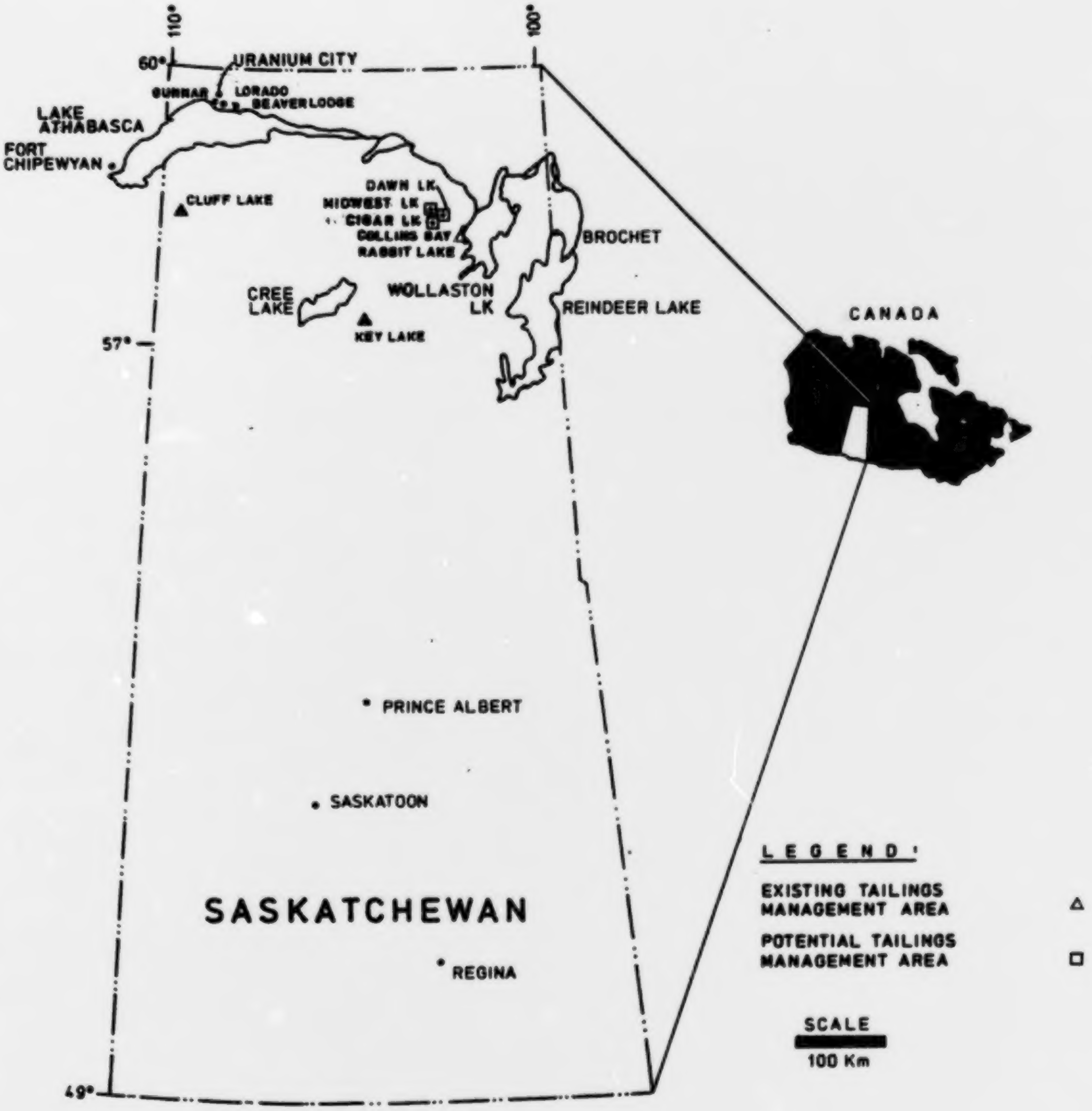
LOCATION OF ELLIOT LAKE AREA

FIGURE 2-2



ELLIOT LAKE AREA TAILINGS SITES
(FROM ENVIRONMENTAL ASSESSMENT BOARD, 1979)

FIGURE 2-3



EXISTING AND POTENTIAL
TAILINGS MANAGEMENT AREAS, SASKATCHEWAN

FIGURE 2-4

Saskatchewan, approximately 115 km northeast of Key Lake. Current reserves are estimated at 130 million kg U_3O_8 at an average ore grade of approximately 14% U_3O_8.

Other smaller deposits (relative to the Cigar Lake deposit) which may be economical in the future, include the Midwest Lake, Dawn Lake and McClean Lake deposits which are all located northwest of the Rabbit Lake area in northern Saskatchewan. Additional deposits associated with the Rabbit Lake-Collins Bay operation of Eldor Mines include the Collins Bay A-Zone and Eagle Point immediately north of Rabbit Lake, and the smaller Raven, Horseshoe and West Bear deposits south of Rabbit Lake.

2.4 Possible Areas

Other possible uranium mining areas in Canada which may become economical in the future include the Baker Lake area in the Keewatin District of the Northwest Territories where the Lone Gull Deposit has been discovered by Urangesellschaft Canada Limited, as well as other exploration sites associated with the Athabasca Basin. These latter sites would not be restricted to northern Saskatchewan, but could also include potential future discoveries on the western edge of the Athabasca Basin within Alberta.

3.0 ORE CHARACTERISTICS AND PROCESSING

3.1 General

The characteristics of tailings pore water will be influenced by a number of factors including:

- mineralogical content of the ore;
- reactivity of ore minerals;
- type of milling process;
- chemicals used in processing;
- chemistry of the tailings solids;
- age of the tailings mass;
- whether or not tailings are actively being deposited; and,
- local climate, particularly precipitation and temperature.

The importance of the factors will vary at each location. Thus, the characteristics of tailings pore water would be expected to vary from deposit to deposit. This section explores the variations in ore characteristics and processing that influence tailings pore water chemistry.

It is important to note that the different mineralogy and chemistry of the Elliot Lake ore compared with the northern Saskatchewan ores would lead to major differences in tailings characteristics. In fact, the difference in ore mineralogy between the northern Saskatchewan deposits themselves causes substantial differences in tailings characteristics. For this reason, the major ore bodies in northern Saskatchewan are discussed individually in the following sections, while the Elliot Lake area is discussed collectively.

3.2 Saskatchewan Ores and Processes

3.2.1 Cluff Lake

Ore Characteristics

The Cluff Lake Phase II ore originates from several ore bodies being developed by the Cluff Mining operations at their Cluff Lake mine site. It is considered a relatively "clean" ore by northern Saskatchewan standards since there is no arsenic or nickel minerals associated with the pitchblende mineralization. A typical mill feed analysis for the Phase II ore is given in Table 3-1.

Ore Processing

The Cluff Lake mining operation is operated by Amok Ltd/Ltee of Saskatoon, Saskatchewan. Phase I of the Cluff Lake operation, started in 1981 and completed in early 1983, was designed and built to recover uranium from the small, but very high-grade, "D" ore body. The Phase I mill was modified and expanded in 1984 to recover uranium from other, lower grade ore bodies in the Cluff lake area. This second phase of operation is referred to as Phase II of the Cluff Lake Mining operations.

The Phase II milling circuit, with a proposed throughput of 230,000 tonnes per year, utilizes conventional crushing, grinding and sulphuric acid leaching of ore ground to minus 429 microns, at atmospheric pressure and low temperature (50°C), using sodium chlorate as oxidant. Liquid-solid separation is achieved by counter-current decantation (CCD) using five thickeners in series. Uranium recovery from pregnant solution is carried out in a solvent extraction circuit where uranium is extracted into an organic phase, which is subsequently stripped with sodium chloride solution to provide a high-grade strip solution for precipitation of uranium with magnesia. The organic phase

TABLE 3-1
CLUFF LAKE PHASE II MILL FEED ANALYSIS

ELEMENT	%
U308	0.35 - 0.7
Th	0.0006
Ra-226	18 Bq/g
Pb-210	17 Bq/g
Th-230	0.2 Bq/g*
Si	33.1
Fe	1.5
S	0.03
Cu	0.008
Zn	0.007
Pb	0.015
Mo	0.02
V	0.02
Ni	0.003
Ti	0.015
Al	5.6
Bi	0.002
Ba	0.02
B	0.007
As	0.001
Ca	0.15
Mg	1.56
Na	0.06
K	1.3
P	0.04
C03	0.04
Cl	0.001
MgO	2.6
K2O	1.57
Si02	70.95
Al203	10.72
Total C	0.01

* analysis believed to be incorrect

(Cluff Mining, 1982)

consists of a tertiary amine (Alamine 336) and isodecanol in a kerosene carrier. Typical concentrations in the organic phase are 5%, 5% and 90% respectively. Spent organic is periodically regenerated with sodium carbonate solution and the sodium chloride solution is partially bled to the tailings neutralization circuit to prevent contaminant build-up in the solvent extraction circuit.

Tailings slurry from the mill (CCD tailings) is neutralized with lime, along with raffinate (barren solution) from the solvent extraction circuit and bleed streams of sodium chloride solution and sodium carbonate solution, as required. The neutralized tailings pulp is pumped to the waste management area where tailings decant water is treated with barium chloride, lime (if necessary) and coagulant. The treated effluent is partially clarified in settling ponds, with final clarification being achieved with sand filters prior to discharge. Sand filter backwash and settled precipitates are returned to the tailings area as required.

3.2.2 Key Lake

Ore Characteristics

The Key Lake uranium deposit consits of two separate ore bodies of uranium mineralization associated with nickel sulphides and arsenides. The uranium ore minerals include euhedral and radially textured pitchblende, sooty pitchblende and smaller amounts of coffinite. Gersdorffite (NiAsS) is the most abundant nickel mineral. Millerite (NiS) is the second most important nickel mineral, followed by niccolite (NiAs) and bravoite $(Fe,Ni)S_2$. Galena, of radiogenic origin, is always present. Within the unaltered basement rocks, pyrrhotite and chalcopyrite have been observed. Extensive intergrowth of the uranium and nickel minerals is present.

Above the ore bearing basement, U-Ni mineralization occurs intermittently disseminated in porous and fractured sandstone and conglomerate. Chlorite schist is the main U-Ni bearing host rock with quartzite host rock having a distinctly lower grade. In both the chlorite and quartzite hosts, limonite, hematite, and carbonate can accumulate in shear zones, cavities, and fractures. Carbon, as graphite, is present throughout the mineralization.

Typical analyses of the Gaertner and Deilmann ore at Key Lake are listed in Table 3-2. The presence of nickel arsenides is evident from the nickel and arsenic assays of the Key Lake ores.

Ore Processing

The Key Lake mine, operated by Key Lake Mining Corporation, is located approximately 200 km north of La Ronge, Saskatchewan. The milling circuit, with a throughput capacity of 720 tonnes per day, consists of semi-autogenous grinding, two-stage acid leaching, liquid-solid separation by counter-current decantation in a series of eight thickeners, solvent extraction with ammonia stripping and precipitation of yellowcake with ammonia.

Leaching of the thickened ore slurry is accomplished in two stages: an atmospheric leach stage in air-agitated pachucas; and, a pressure leaching stage at 450 kPa and 60° C in autoclaves with oxygen over-pressure to ensure oxidizing conditions. Terminal acidities are maintained at approximately 50g/L H_2SO_4. Oxygen is generated on site by a package oxygen plant.

Uranium in the pregnant solution from the CCD circuit is upgraded and purified in a solvent extraction circuit utilizing a tertiary amine organic phase and ammonia stripping of loaded organic. The pregnant strip liquor is precipitated with ammonia to produce yellowcake. Barren strip solution from this circuit is recycled to the solvent extraction circuit. Ammonium

TABLE 3-2
TYPICAL ANALYSIS OF GAERTNER AND DEILMAN ORE BODIES

ELEMENT	GAERTNER ORE (%)	DEILMANN ORE (%)
U308	2	2.9
Ra-226	222 Bq/g	N/A
Si0	50	50
Fe	3.5	3
S	1	0.8
Cu	0.03	0.09
Zn	0.08	0.03
Mo	0.006	0.03
V	0.08	0.09
Ni	2.5	1.1
Co	0.08	0.08
Ti	0.4	0.6
Al	9	10.3
As	1.5	1.1
Ca	0.4	0.4
Mg	3	2.9
Na	0.7	0.9
K	0.6	1.5
F	0.05	N/A
P205	0.16	0.15
C02	1	0.8
Cl	0.05	N/A

(from Clarke et al, 1980)

sulphate concentrations in the strip liquor are controlled by removing a bleed stream of clarified strip solution to an ammonium sulphate crystallization circuit. The ammonium sulphate crystals are produced and marketed as fertilizer-grade material. Organic is regenerated with sodium carbonate solution as required.

The leach tailings from the CCD circuit are neutralized with lime to pH 11 or greater, and liquid waste streams are neutralized and treated in a separate waste treatment circuit. Raffinate and spent sodium carbonate solution from the solvent extraction circuit, along with seepage and runoff from the tailings pond, are neutralized with lime and the resulting precipitate is thickened and discharged to the tailings pond with the neutralized mill tailings. The liquid mill effluent is then further treated with barium chloride and lime to remove radium and heavy metal contaminants. The minor amounts of additional precipitate are removed in a thickener and, if necessary, the final treated effluent is clarified in a leaf clarifier prior to pH re-adjustment and transfer to monitoring ponds. The effluent is then discharged to the environment if contaminant levels are acceptable, or recycled for further treatment if neccessary.

Minewater from the open-pit mining operation is used as process water and any excess contaminated water is treated in an ion exchange circuit where radium is removed by a radium-selective ion exchange complexer. To date, disposal of loaded resin from this circuit has not been required. When this becomes necessary it will probably be pumped to the tailings area along with the neutralized mill tailings.

The tailings area at Key Lake utilizes a layered tailings deposition technique where tailings slurry is deposited in thin layers in a rotational sequence and allowed to consolidate by evaporation and drainage. This systematic layered deposition method is claimed to provide a partially saturated, moisture retaining tailings mass of low permeability, with minimum potential for ongoing seepage. A sand bed underseal and perforated drainage pipe system removes vertical seepage during the deposition phase, and the main embankment incorporates a pervious upstream zone to continuously decant precipitation and supernatant water. This "seepage and runoff" is pumped to lined water reservoirs at the mill site where excess water is used as process water or treated for radium removal in the ion exchange circuit.

3.2.3 Rabbit Lake and Collins Bay

Ore Characteristics

The Rabbit Lake ore which is exhausted (1985) at the Eldor Mines operation in northern Saskatchewan was comparable to the Cluff Lake ore with similarly low nickel and arsenic contents. The mineralization consisted mainly of pitchblende and coffinite but skodowsite was a common secondary mineral along with minor amounts of kasolit, woelsendorfite, uranophane and Boltwoodite. Minor amounts of galena, pyrite, rutile, nickeline and marcasite were the metallic minerals associated with the uranium mineralization. Phyllosilicates and calcite were the most common gangue minerals. Elemental assemblages included vanadium, molybdenum, nickel, copper, lead, barium, boron, magnesium and phosphorus.

The Collins Bay B-Zone ore body, containing pitchblende and coffinite as the uranium mineralization, is different from the Rabbit Lake ore by virtue of its arsenic, nickel and clay content. Associated mineralization includes gersdorffite, skutterudite, nickeline, millerite, galena, chalcopyrite and pyrite. Elemental assemblages contain silver, arsenic, cobalt, chromium, copper, nickel, lead, titanium, vanadium and zirconium. Modifications to the Rabbit Lake mill have been necessary to accommodate the different composition of the B-Zone ore.

The Collins Bay A-Zone ore body contains pitchblende associated with rammelsbergite, pararammelsbergite and some galena and sphalerite. The Eagle Point ore contains pitchblende, coffinite, uranophane and boltwoodite. The Eagle Point ore zones are believed to consist of relatively "clean" uranium mineralization.

Typical analyses for the Rabbit Lake ore and the Collins Bay B-Zone ore are presented in Table 3-3.

Ore Processing

The Rabbit Lake mining operation, located on the west side of Wollaston Lake in northen Saskatchewan, was started by Gulf Minerals in 1975 and has been operated by Eldorado Resources Limited since 1982.

The Rabbit Lake mill, with a capacity of 2,000 tonnes per day, utilized a sulphuric acid atmospheric leach with sodium chlorate oxidant, CCD liquid-solid separation, solvent extraction with ammonium sulphate stripping and ammonia precipitation of uranium. Mill tailings were bulk neutralized with lime prior to disposal to the tailings pond area. Tailings decant water is treated with barium chloride and clarified in a series of three settling ponds and sand filters prior to discharge to Hidden Bay.

The existing Rabbit Lake mill has recently (1985) been modified to accommodate the Collins Bay B-Zone ore which contains arsenic and nickel-bearing minerals. The main changes to the milling circuit include the use of strong acid (400 g/L H_2SO_4) stripping in the solvent extraction circuit and precipitation of uranium with hydrogen peroxide, replacing ammonia. Pre-treatment of pregnant strip liquor is necessary prior to uranium precipitation in order to ensure acceptable yellowcake purity.

TABLE 3-3
TYPICAL ANALYSIS OF RABBIT LAKE/COLLINS BAY B-ZONE ORE

ELEMENT	RABBIT LAKE (%)	COLLINS BAY B-ZONE (%)
U308	0.3	0.6
Th02	N/A	0.003-0.04
Fe	N/A	1-3
S	N/A	0.1
Mo	0.002	0.01-0.02
V	0.02	0.02-0.05
Ni	0.01	0.4
As	0.003	0.5
P04	0.2	0.02
C02	2-3	0.2
Ra-226 (est)	30 Bq/g	60 Bq/g

(from Gulf Minerals Canada Limited, 1980a)

Treatment of mill tailings has been changed to separate neutralization of CCD tailings and allow separate treatment of mill liquid effluents for removal of radium and heavy metal contaminants. Minewater from the Collins Bay B-Zone open pit mine will be used as process water and any excess will be treated with lime, ferric sulphate, and barium chloride for removal of arsenic, heavy metals and radium. Waste precipitates are combined with the neutralized mill tailings. Clarification of treated effluent will be accomplished by sand filtration.

The tailings containment method approved for this operation is in-pit disposal in the mined-out Rabbit Lake pit. Neutralized mill tailings are dewatered by filtration using disc filters in order to accelerate the consolidation of tailings when placed in the Rabbit Lake pit. Tailings pore water resulting from further consolidation of tailings in the pit are collected at the base of the pit and pumped via a raise to surface for treatment in the mill effluent treatment circuit.

3.2.4 Midwest Lake Area

The four potential ore bodies at Cigar Lake, Midwest Lake, McClean Lake and Dawn Lake have been grouped together as possible Saskatchewan sources.

Cigar Lake

The bulk of the uranium in the Cigar Lake ore body occurs as uraninite with some pitchblende. Coffinite is also present in relatively small quantities. The sulfo-arsenides of NiCo can locally be major components of the ore with the main minerals being gersdorffite, skutterudite, niccolite, bravoite, cobaltite and rammelsbergite. Many sulphide minerals, including pyrite, are present. The average grade of Cigar Lake ore is given in Table 3-4.

TABLE 3-4
TYPICAL ANALYSIS OF CIGAR LAKE ORE

ELEMENT	%
U308	14.5
Cu	0.7
Zn	0.04
Pb	1.2
Mo	0.14
Ni	1
Co	0.15
As	1.7
Ra (est)	1450 Bq/g

(Cigar Lake Mining Corporation, 1985, Private Correspondence)

Midwest Lake

The principal minerals of interest of the Midwest project uranium rich zone include pitchblende, coffinite, gersdorffite, niccolite and rammelsbergite. Also present are minor amounts of chalcopyrite, galena, bismuthinite, polydimite, and cobalt and silicate minerals. The pitchblende-nickel arsenide veins are associated with kaolinite-chlorite and sericite. The gangue in the unconformity is sericite-hematite clay. A typical analysis of the Midwest material is given in Table 3-5.

McClean Lake

The McClean uranium mineralization is concentrated in four zones. The sulphide zone contains bravoite-pyrite, coffinite, uraninite, iron chlorite, illite, siderite and chalcopyrite. The arsenide zone contains aresenide-illite intergrowths, pararammelsbergite, niccolite, intergrowths of coffinite-pararammelsbergite and illite with subordinate nicollite, gersdorffite and arsenides. The oxide zone contains nodular intergrowths of coffinite-pararammelsbergite in hematized clay matrix.

Although no typical analysis of the McClean Lake material is available for the purpose of this study it can be presumed that it would be similar to the analysis of the Midwest ore considering its similar mineralogical characteristics.

Dawn Lake

The Dawn Lake deposit is made up of several "pods" and hence the material can be expected to vary in uranium grade and elemental assemblage. The mineralogy of the deposit indicates pitchblende, uraninite and coffinite as uranium minerals with nickel arsenides, geothite and carbonates present.

TABLE 3-5
TYPICAL ANALYSIS OF MIDWEST LAKE ORE

ELEMENT	%
U308	2.2
Ra-226	275 Bq/g
L.O.I.	3.1
Si02	76
Fe	1.3
S	1.1
Cu	0.1
Zn	0.07
Mo	0.06
V	0.08
Ni	1.7
Co	0.2
Ti	0.3
Al	3.2
Mn	0.04
Cr	0.02
As	3.2
Ca	0.1
Mg	0.5
Na	0.1
K	1.2
F	0.05
P	0.03
C02	0.5
Cl	0.03
Zr	0.05
Rb	0.05
Sr	0.01

(from Melis et al, 1983)

Host minerals include quartz, chlorite, illite, sericite, and titanium oxides.

3.3 Elliot Lake Area Ores and Processes

Ore Characteristics

The conglomerate ores being processed at the four uranium mines in Elliot Lake area are all of the same mineralogical type. They are pyritic conglomerates, consisting essentially of quartz and chert pebbles in a matrix of sericitic, feldspathic quartzite containing pyrite, pyrrhotite, titanium minerals, monazite and zircon. There are a variety of radioactive minerals including brannerite, uraninite, thucolite, uranotholite, uranothorianite, coffinite, allanite, xenotime and gummite. Brannerite, uraninite, monazite, and uranothorite are the most important ore minerals.

A typical ore analysis for Elliot Lake conglomerate is given in Table 3-6. Although specific values would vary between each operation the values given are average values or expected ranges for the elements listed. It is also noted that the pyrite-pyrrhotite content is approximately 7% and the silica content is generally greater than 75%.

Denison Mine Ore Processing

The Denison uranium mine has been in continuous operation since 1957 with the mill throughput increasing in stages to the present capacity of 11,000 tonnes per day.

The milling circuit is typical of Elliot Lake uranium operations. Ground ore is leached in pachucas (air agitated tanks) with sulphuric acid at elevated temperature (80° C) and ambient pressure. The uranium-rich solution in the leach pulp is separated by thickening (wash thickeners) and

TABLE 3-6
TYPICAL ANALYSIS OF ELLIOT LAKE URANIUM ORE

ELEMENT	%	ELEMENT	%
U308	0.1	Mn	0.004
Th	0.04	Cr	<0.001
Ra	11 Bq/g	Ba	0.02
L.O.I.	3	Cd	<0.001
Si02	80	Sb	<0.001
Fe	3-5	Sn	<0.001
S	2-4	B	0.0004
Cu	0.007	As	<0.005
Zn	0.005	Ca	0.1
Pb	0.04	Mg	0.2
Mo	<0.001	Na	0.1
V	<0.001	K	2
Ni	0.003	F	0.02
Co	0.005	S04	<0.10
Ti	0.08	P04	0.1-0.2
Al	3-4	C02	0.2
Bi	<0.001	Cl-Br-I	< 0.005
Ag	<0.002	NH3	0.02

(from Melis Consulting Engineers Limited, 1985, Private Correspondence) filtration (drum filters). The uranium is then recovered from solution by ion exchange and a concentrated eluate is produced by nitric acid elution of the loaded resin. Uranium in the concentrated eluate is precipitated with ammonia at pH 7 to produce yellowake (ammonium diuranate) which is dewatered, dried and packaged in drums for shipment.

Additional uranium is recovered from the Denison operation by bacterial leaching of mined-out or low-grade stopes underground. The acidic minewater is pumped to the mill where it is neutralized with lime to pH 9-10 and the precipitate removed in a thickener for feeding to the leaching circuit for recovery of the uranium. The clarified minewater from this operation is used as mill process water.

Tailings slurry from the mill is bulk neutralized with lime to pH 10-11 and pumped to the Long Lake tailings basin. Tailings decant water is treated with $BaCl_2$ for removal of radium and discharged to the Stollery Lake settling ponds for clarification and separation of the precipitated sludge prior to discharge to the Serpent River system.

Quirke Mine Ore Processing

The Quirke mine and mill was operated from 1956 to 1961 and then re-started in 1968. The present mill throughput is 6,400 tonnes per day.

The milling circuit is similar to the Denison operation with the only difference being in the liquid/solid separation process where the uranium solution is separated from the leach slurry by wash cyclones and counter-current decantation in six stages of thickeners. Yellowcake is produced by precipitation of ion exchange eluate with ammonia. Uranium recovery from minewater is achieved by precipitation of acidic minewater with lime.

Tailings slurry is neutralized with limestone to pH 3.5 and lime to pH 10-11 in a series of 5 tailings neutralization pachucas.

The neutralized slurry is pumped to the Bud Lake tailings basin where tailings decant water and acidic seepage water is treated with lime and $BaCl_2$. The treated water is clarified in a series of three unlined settling ponds prior to discharge to the Serpent River system.

Panel Mine Ore Processing

The Panel operation was active from 1958 to 1961 and was re-activated again in 1979. The mill throughput capacity is 3,000 tonnes per day.

The milling process is the same as the Denison operation except in the ion exchange circuit, where loaded resin is eluted with 10% sulphuric acid and uranium is precipitated with magnesium hydroxide. As with the other Elliot Lake operations, uranium is recovered from minewater by precipitation with lime.

Tailings slurry is bulk neutralized with limestone and lime, then pumped to the Strike Lake tailings management area. Tailings decant water is collected and treated with lime and $BaCl_2$ for radium removal and neutralization. The treated effluent is clarified in hypalon-lined settling ponds prior to discharge to Quirke Lake.

Stanleigh Mine Ore Processing

The Stanleigh mine and mill was operated from 1958 to 1960 and went back into production in 1983.

The Stanleigh mill circuit, with a capacity of 4,500 tonnes per day, is very similar to the Panel operation except that a semi-autogenous grinding mill is used as opposed to the conventional rod-pebble mill used at Panel. Liquid-solid separation is carried out using horizontal belt filters, and continuous moving bed ion exchange is used to recover uranium from solution. Magnesia precipitation of uranium is practiced.

Tailings slurry is bulk neutralized with limestone and lime and pumped to the Crotch Lake tailings area where the neutralized tailings are deposited over old tailings from the previous Stanleigh and Milliken operations. Tailings decant water is treated with lime and $BaCl_2$ for neutralization and removal of radium. Clarification of treated effluent is accomplished by sand filtration in dual-media sand filters. The precipitated sludge, as sand filter backwash, is returned to the tailings area.

3.4 Ores From Other Areas

Lone Gull

The Lone Gull deposit in the Baker Lake area of the Northwest Territories has mineralogical characteristics which are similar to the northern Saskatchewan deposits, except for much lower arsenic and heavy metal content. The high aluminum content may be an indication of a high clay content in the ore. A typical analysis of the Lone Gull deposit is given in Table 3-7.

The most common uranium minerals in the Lone Gull deposit are pitchblende and coffinite with minor amounts of uranophane being identified. Uranium vanadates have been identified and uraniferous titanates are possibly present in minor amounts. The pitchblende and coffinite contain fine grained inclusions of marcasite, pyrite, chalcopyrite, rutile and, less commonly, galena. The most common sulfide mineral is marcasite with marcasite-pyrite-pitchblende-coffinite-intergrowths being fairly common. The common gangue minerals are quartz, sercite/illite and chlorite. Minor

TABLE 3-7
LONE GULL ORE DEPOSIT ANALYSIS

ELEMENT	%
U308	0.75
Th02	0.002
Si02	60
Fe	2.7
S	0.1
Cu	0.002
Pb	0.02
Mo	0.02
V	0.07
Ni	0.002
Co	0.003
Ti	0.3
Al	9.9
Mn	0.04
Sb	0.007
B	0.05
As	0.03
Ca	0.3
Mg	1.2
Na	0.09
K	4.1
Zr	0.02
Hg	0.00005
Ag	4.2 g/t
Au	0.4 g/t
Ra-226	75 Bq/g

from Stuart,1985, Private Correspondence) smectite group clays are locally present, and minor to trace amounts of barite, apatite and rare earth phosphates have also been detected.

Blizzard

Uranium in the Blizzard mineralized zone occurs as calcium and magnesium uranyl phosphates, autuite and salecite with gangue minerals being quartz, feldspar, chlorite, mica, zircon, garnet and hematite.

Kitts/Michelin

The Michelin deposit contains only pitchblende as uranium mineralization with higher grade mineralization commonly associated with hematite. Mineralized zones also contain large amounts of calcite with accessory minerals including fluorite and molybdenite with sparse occurrence of magnetite and pyrite.

The Kitts deposit also contains pitchblende as the uranium mineralization which is associated with finely desseminated pyrrhottite, pyrite, ilmenite and hematite. The Kitts material also contains large amounts of calcite. Molybdenum and vanadium have also been noted.

4.0 LEACHATE CHEMISTRY

4.1 Saskatchewan Leachates

The chemistry of tailings pore water resulting from processing northern Saskatchewan uranium deposits will vary depending on the uranium ore being processed and what process is being used. In addition, the reagents being used to process northern Saskatchewan uranium deposits have a direct effect on tailings pore water chemistry.

As discussed in Section 3.0, the three uranium producers in northern Saskatchewan utilize different reagents for recovering uranium. Cluff Lake operations use sodium chlorate oxidant in leaching and sodium chloride for stripping the organic in the solvent extraction circuit. Magnesium oxide (magnesia) is used for precipitating uranium as a final product.

Key Lake, on the other hand, utilizes oxygen as a leach oxidant but uses ammonia for stripping the organic and for final precipitation of uranium.

The Rabbit Lake operation used sodium chlorate oxidant and ammonia for stripping of the organic, followed by ammonia precipitation of yellowcake. For processing the Collins Bay B-Zone ore sodium chlorate oxidant is maintained but sulphuric acid stripping of the organic in the solvent extraction circuit, followed by hydrogen peroxide precipitation of uranium as a final product, is employed.

Consequently, significant sodium chloride levels would be expected in the Cluff Lake tailings pore water, with actual levels being dependent on the amount of sodium chlorate used in leaching and the amount of sodium chloride recycled in the mill circuit. Typical Cluff Lake tailings pore water analysis was not available for inclusion in this report, but because of the relatively "clean" nature of the Cluff Lake ore it would be expected to be similar to

Rabbit Lake tailings pore water with the only exception being higher sodium chloride levels.

Key Lake, on the other hand, would not have any significant levels of sodium or chloride ions in the tailings pore water, but would be expected to contain some ammonia depending on the efficiency of the ammonium sulphate crystallization plant in removing excess ammonia from process streams.

The tailings pore water from the Rabbit Lake operation would be expected to contain chloride ions and ammonia due to the use of both chemicals in the process. On the other hand, tailings pore water from processing Collins Bay B-Zone ore would contain sodium and chloride ions.

Tailings pore water from processing nickel arsenide ores would be expected to contain a certain amount of arsenic and heavy metals even though these elements would be precipitated from waste solutions in the waste treatment circuit. In this respect Cluff Lake and Rabbit Lake tailings pore water would be different than the Key Lake tailings pore water.

An indication of the type of tailings pore water which can be expected from processing various northern Saskatchewan uranium ores is provided in Tables 4-1, 4-2, and 4-3.

A recent study of the Key Lake tailings (Knight and Piesold Ltd., 1985) for The National Uranium Tailings Program, has provided an indication of the water chemistry associated with the Key Lake tailings. These results are reproduced in Table 4-1. A more complete analysis of incoming tailings liquids and tailings seepage is provided for comparison in Table 4-2. It should be noted that pH as low as 6.4 in fresh tailings is abnormal. It is understood that this low sample was taken during mill startup. (It can also be noted here that two samples of tailings solids analyzed for cation exchange capacity gave results of 2.2 and 5.43 meq/100 g).

TABLE 4-1
KEY LAKE TAILINGS WATER CHEMISTRY

ELEMENT	TAILINGS EFFLUENT	TAILINGS RUNOFF EFFLUENT	PORE WATER	SEEPAGE
As ppm	0.763-4.6	-	0.26-2.2	0.062-0.076
Cr ppm	0.008-0.024	0.011-0.022	<0.005	0.004-0.014
Mo ppm	0.11-3.7	0.58-1.3	0.43-1.2	0.48-0.85
Ni ppm	0.01-0.29	0.005-0.011	0.016-0.087	0.041-0.094
Pb ppm	<0.005-0.28	<0.005-0.02	<0.02-0.04	<0.005-0.02
Si ppm	0.2-0.8	-	1.8-4.1	1.3
U ppm	0.0035-0.1	0.0032-0.013	0.0014-0.005	0.04-0.13
Zn ppm	0.002-0.47	0.001	0.02-0.032	0.06-0.21
W ppm	0-1.1	0.45-0.89	0.23-0.25	0.06-0.31
Ra 226 Bq/L	25-420	270	9.5-55	10-45
Pb-210 Bq/L	0.4-25	3	0.13-0.7	0.7-0.45
Th-230 Bq/L	0.5-4.0	2	0.08-1.6	0.2-1.4
Po-210 Bq/L	0.5	0.15	-	0.09
pH	6.4-12	11.3-11.5	9.3-11.1	7.1-7.4
Ca	520-1050	655-780	582-627	374-550
SO4	1310-3450	1590-1720	1340-1650	1150-1470

(from Knight and Piesold Ltd. 1985)

TABLE 4-2
KEY LAKE TAILINGS WATER AND SEEPAGE ANALYSIS

ELEMENT	INCOMING TAILINGS	TAILINGS SEEPAGE EFFLUENT	ELEMENT	INCOMING TAILINGS	TAILINGS SEEPAGE
Ag ppm	<0.001	<0.001	Pb-210 Bq/L	0.4-45	0.07-0.45
Al ppm	0.-0.15	0.-6.1	Po-210 Bq/L	0.5	0.09
As ppm	0.8-4.6	0.062-0.076	Ra-226 Bq/L	25-420	10-45
B ppm	0.02-0.52	0.02-0.04	Th-228 Bq/L	0.07-0.35	0.09
Ba ppm	0.01-0.12	0.04-0.061	Th-230 Bq/L	0.5-4.5	0.2-1.4
Be ppm	<0.001	<0.001	Th-232 Bq/L	0.02-0.4	0.07
Ca ppm	520-1050	374-550	NH3-N ppm	11-33	34
Cd ppm	0-0.004	0-0.01	Cl ppm	14-387	16
Co ppm	<0.001	0-0.009	OH ppm	104-504	Nil
Cr ppm	0.008-0.024	0.004-0.014	NO3-N ppm	0.01-0.06	0.03
Cu ppm	0.005-0.009	0.007-0.009	NO2-N ppm	0.02-0.31	<0.005
Fe ppm	0.032-0.064	0.042-3.8	SO4 ppm	1310-3450	1150-1470
K ppm	4.9-30.0	7.8-8.9	pH	6.4-12.1	7.1-7.4
Mg ppm	0.1-510	0.63-3.9	Eh mV	93-395	-243+424
Mn ppm	0-1.9	0.057-4.2	TDS ppm	2760-5220	2160
Mo ppm	0.1-3.7	0.48-0.85	Conductivity umho/cm2	3130-6810	2030
Na ppm	15-210	24-47	Isodecanol ppb	-	100
Ni ppm	0.01-0.29	0.0411-0.094	Kerosene ppb	-	0.2
P ppm	0.050-0.38	0.05-0.08	Tert. Amines ppb	-	1
Pb ppm	0-0.28	0-0.02			
Sb ppm	0-0.002	0.002			
Se ppm	0.001-0.02	<0.001			
Si ppm	0.2-0.8	1.3			
Ti ppm	<0.001	<0.001			
V ppm	0.06-0.21	0-0.07			
W ppm	0-1.1	0.06-0.31			
Zn ppm	0.002-0.47	0.06-0.21			
Zr ppm	<0.001	<0.001			
U ppm	0.004-0.1	0.04-0.13			

(from Knight and Piesold Ltd., 1985)

TABLE 4-3
RABBIT LAKE/COLLINS BAY B-ZONE TAILINGS PORE WATER CHEMISTRY

ELEMENT	RABBIT LAKE (ppm)	COLLINS BAY B-ZONE (ppm-est)
pH	5.0-8.5	
Conductivity (umho/cm2)	3700-4950	4802
U	0.3-0.5	<0.05
Total Kjehldahl N	358	5.1
NH3	321	3.8
NO3	5	1
Cl	210	763
SO4	6350	2970
Ca	468	726
Mg	956	<0.1
HC03	35	28
CO3	0	28
P total	0.35	<0.03
P ortho	0.03	<0.03
Total Organic C	12	28
BOD	2	20
As	0.001	1.5
Ba	0.1	<0.5
B	0.8	0.3
Cd	0.007	0.03
Cr	0.02	<0.05
Co	0.15	0.1
Cu	0.06	<0.05
F	1.1	0.3
Fe	0.25	0.1
Pb	0.1	0.3
Mn	0.4	<0.05
Hg	<0.0001	<0.0001
Ni	0.4	1.5
K	31	72
Ag	0.02	0.02
Na	154	450
V	<0.01	<0.2
Zn	0.06	<0.2
Ra-226 (total) Bq/L	0.8-18.4	N/A
Po-210 Bq/L	1.5-4.3	N/A
Th-230 Bq/L	1.6-5.5	N/A

(from Melis Consulting Engineers Limited, 1985, Private Correspondence)

Typical Rabbit Lake tailings water analysis and the expected pore water analysis from processing Collins Bay B-Zone are detailed in Table 4-3. As noted earlier, the Cluff Lake tailings pore water would be similar in nature to the Rabbit Lake tailings pore water except for no ammonia content and higher sodium chloride in the Phase II effluent.

The tailings pore water characteristics that could be expected for the undeveloped uranium deposits in northern Saskatchewan can be predicted in part by the ore mineralogy and typical ore analysis for these deposits. However, it should be noted that the most significant effect on tailings pore water chemistry will be the recovery processes used in any new operation as well as the type of reagents used in the process. Since these have not been identified, it is difficult to predict with any degree of confidence the type of tailings pore water which can be anticipated in the future development of additional uranium properties in northern Saskatchewan.

Processing of Cigar Lake, Midwest, Dawn Lake, McClean ores would likely result in similar water chemistry to that experienced at the Key Lake operation, although final process selections will have a direct bearing on this. The level of arsenic and heavy metals present in the pore water will be more or less dependent on the amount of these elements present in the ore, as well as on the type of waste treatment used. The high-grade nature of the Cigar Lake ore may cause higher levels of radionuclides in the tailings pore water when this ore is processed.

4.2 Elliot Lake Area Leachates

The main concern with the Elliot lake area is the acidic nature of the oxidized tailings due to the acid-generating potential of contained pyrite. Neutralized (active) tailings sites will have different pore water characteristics compared with inactive tailings sites where oxidization of pyrite has taken place, creating acidic pore water. The acidic pore water leads to greater mobility of contained ions and hence pore water from oxidized tailings will contain a higher amount of dissolved solids compared to neutralized tailings pore water.

The chemical characteristics of pore water for both neutralized and oxidized tailings, typical of the Elliot Lake area, are presented in Table 4-4.

4.3 Leachate Chemistry: Other Areas

The Lone Gull deposit in the Baker Lake area of the Northwest Territories contains minor levels of arsenic and heavy metals; hence, the tailings pore water from development of this deposit would be similar in nature to the Rabbit Lake tailings pore water. However, because of local climatic conditions, the tailings would likely be permanently frozen, with only a thin active layer.

There is insufficient information available about any possible process for the Blizzard deposit to enable prediction of typical tailings pore water chemistry. Since the uranium occurs as a phosphate mineral, processing would differ from other current operations; consequently certain aspects of the tailings pore water would be different.

The Kitts/Michelin deposits contain a relatively large amount of calcite and this would be taken into consideration when devising a process. Process modifications might be necessary to minimize acid consumption if acid leaching were chosen for this ore. On the other hand, if an alkali leach were chosen, it would lead to a substantially different type of tailings pore water as opposed to the currently producing acid leaching circuits.

TABLE 4-4
ELLIOT LAKE AREA TAILINGS PORE WATER CHEMISTRY

ELEMENT	OXIDIZED TAILINGS (ppm)	NEUTRALIZED TAILINGS (ppm)
TDS	10,000-40,000	2500-3500
Fe	3,000-15,000	<1
S04	5,000-25,000	1,000-2,000
Ca	400-600	400-500
Mg	100-300	N/A
Na	10-20	N/A
K	20-100	N/A
Mn	1-20	N/A
Al	20-80	N/A
Cu	0.01-0.02	N/A
Co	0.1-3.0	N/A
Zn	0.1-0.2	N/A
Pb	0.1-0.3	N/A
Ni	0.5-1.5	N/A
SiO2	10-20	N/A
Cl	10-20	N/A
NH3 as N	0-100	10-100
N03 as N	0-100	10-50
pH	2-6	8-10
U308	1-2	0.01-0.03
Ra-226	0.4-3 Bq/g	10-55 Bq/g

(from Morin, 1985)

5.0 CLUFF LAKE AREA

5.1 Detailed Location

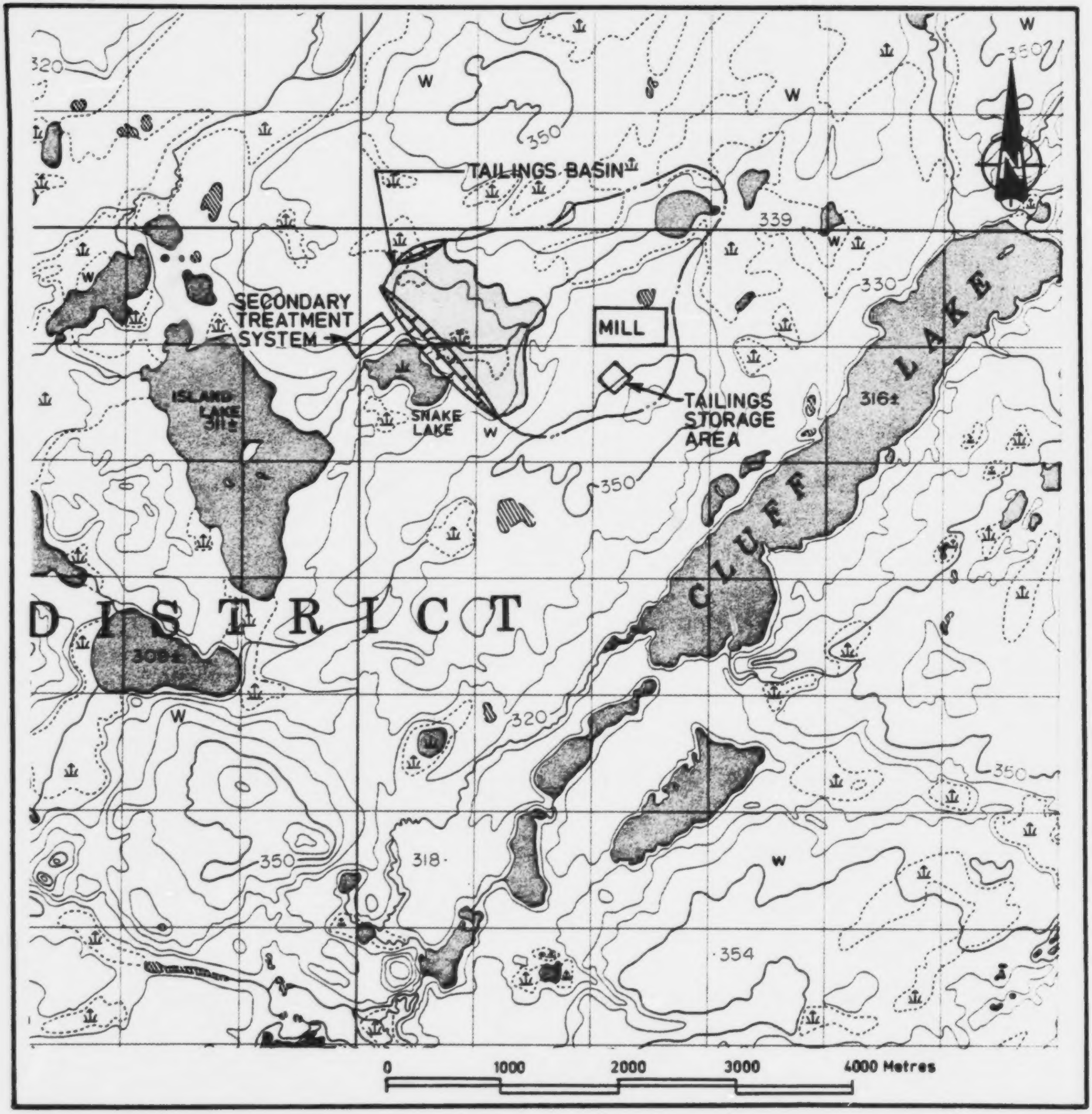
The Cluff Lake mine site is located approximately 97 km south of Lake Athabasca and 35 km east of the Saskatchewan-Alberta border. The map location is 58° 23'N latitude and 190° 32'W longitude. The detailed study area is shown in Figure 5-1.

5.2 Climate

Meterological data for Uranium City (Sask.), Cree Lake (Sask.) and Fort Chipewyan (Alta.) from 1951 to 1980 have been reviewed to characterize the climate of the Cluff Lake area of northern Saskatchewan. Cluff Lake is between, and approximately 150 km from these meteorological stations.

The mean monthly temperature in the Cluff Lake area is estimated to range from -28° C in January to 16° C in July. Figure 5-2 shows the distribution of the monthly temperatures through an average year. Based on these temperatures the potential evapotranspiration for this region has been calculated using the Thornthwaite Method. The potential evapotranspiration is estimated to be 463 mm per year.

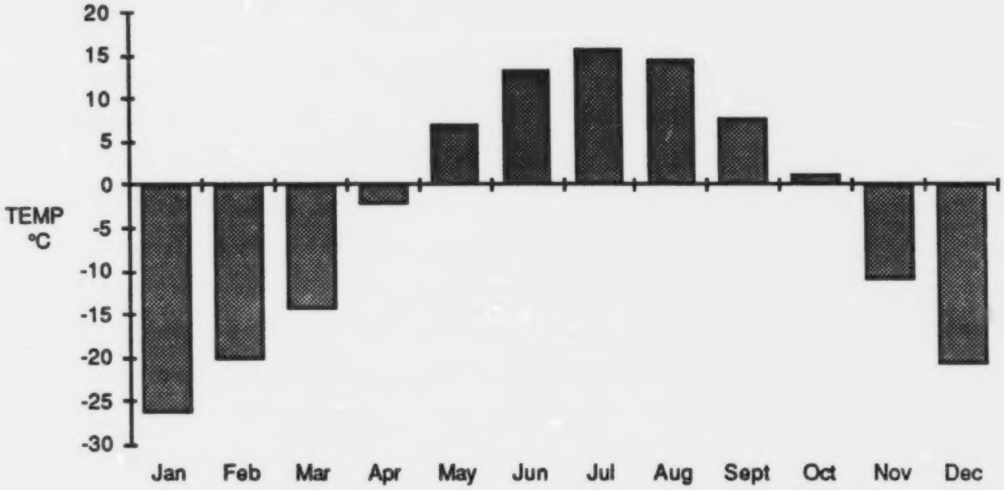
The mean annual precipitation in the Cluff Lake area is estimated to the 379 mm. The precipitation is not evenly distributed throughout the year. Generally, the colder months of October to April each receive between 15 mm and 30 mm of precipitation, mainly as snow. The summer months each receive between 42 mm and 67 mm of rainfall. The distribution of this precipitation for an average year is shown in Figure 5-3. There is also some variation in the total precipitation from year to year. It is likely that the precipitation in the Cluff Lake area will range from 314 mm to 445 mm during



SITE PLAN

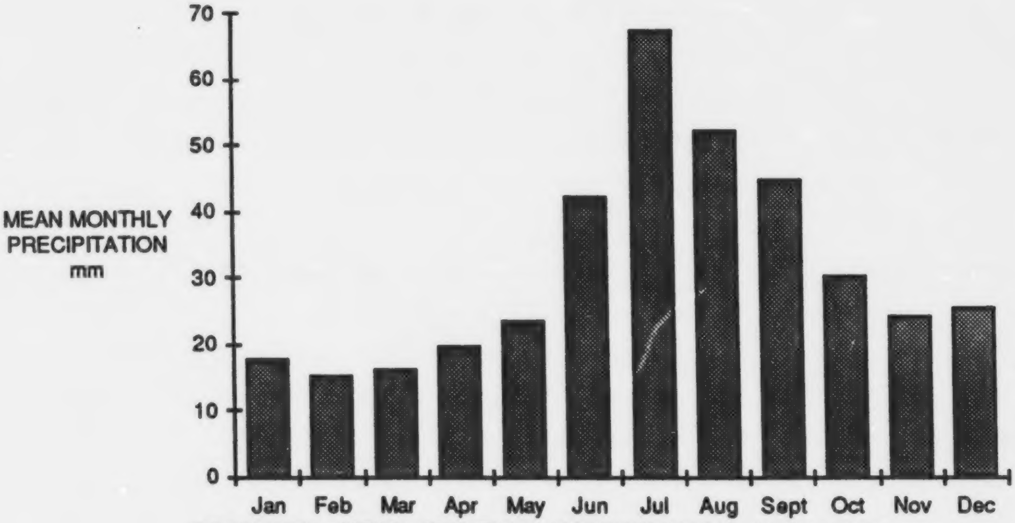
CLUFF LAKE TAILINGS MANAGEMENT AREA
(FROM CLUFF MINING, 1982)

FIGURE 5-1



**ESTIMATED MEAN MONTHLY TEMPERATURE (1951-1980)
FOR CLUFF LAKE TAILINGS AREA**

FIGURE 5-2



**ESTIMATED MEAN MONTHLY PRECIPITATION (1951-1980)
FOR CLUFF LAKE TAILINGS AREA**

FIGURE 5-3

13 out of 20 years. This range is based on one standard deviation of data about the mean value.

Based on an annual precipitation of 379 mm and a potential evapotranspiration of 463 mm, there is an annual potential water deficit of 84 mm in the Cluff Lake area. Acknowledging the variation in annual precipitation it is also likely that the potential annual water balance could range from a deficit of 18 mm to a deficit of 150 mm, for 13 years out of 20. Monthly water balances are calculated as part of the Thornthwaite procedure (Table 5-1). Figure 5-4 shows the estimated distribution of the water balance on a monthly basis for an average year. Figure 5-5 is included to show the likely ranges of water balances on a monthly basis for 13 out of 20 years. These ranges are based on one standard deviation of data about the mean value. Because the water balance data from individual months may differ in how much they vary from the norm (and to a certain extent cancel out) one cannot simply add the monthly ranges shown in Figure 5-5 and consider it as an "annual" range.

Gray (1970) estimates that the Cluff Lake area has 25 mm or more snow cover for approximately 180 days/year. The mean date of formation of the snow pack is approximately 01 November annually and it persists until approximately 01 May the following year. The median depth of snow pack on 28 February annually is approximately 400 mm. The date of snow pack formation (01 November) also approximates the date of formation of ice cover on the lakes. The ice cover persists until approximately 10 May the following year.

Extreme precipitation will substantially exceed the mean events described above. The probable maximum precipitation is of most interest. The probable maximum precipitation has been estimated (Knight and Piesold, 1981a; Whiting et al, 1972) to be 75 mm in 72 hours. Wigham (personal communication) describes rainfall events as 267 mm in 135 minutes at Buffalo Gap, Saskatchewan, and 305 mm in 12 hours in East Trout Lake, Saskatchewan. Thus, it appears the probable maximum precipitation event in the order of 300 mm in

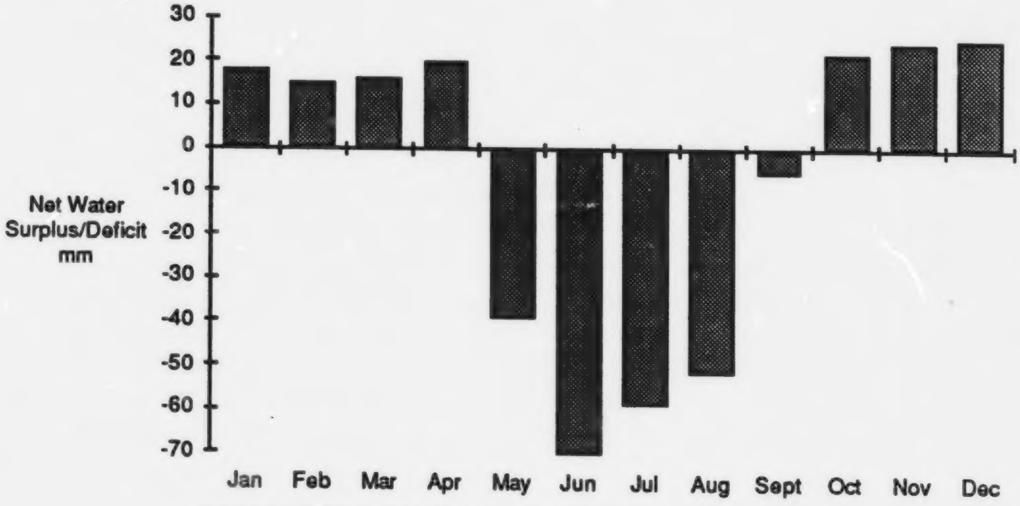
TABLE 5-1

AVERAGE WATER BUDGET CALCULATION FOR CLUFF LAKE TAILINGS AREAS

MONTH	MEAN TEMP (C)	EST * EVT (mm)	MEAN PRECIP. (mm)	NET WATER BALANCE (mm)
Jan	-26.2	0	18	18.0
Feb	-20.1	0	15.3	15.3
Mar	-14.4	0	16.2	16.2
Apr	-2.1	0	19.7	19.7
May	7	62.4	23.5	-38.9
Jun	13.3	112.4	42.4	-70.0
Jul	15.9	126.3	67.3	-59.0
Aug	14.5	103.5	52.1	-51.4
Sept	7.7	50.5	44.9	-5.6
Oct	1.1	8.4	30.3	21.9
Nov	-11	0	24.3	24.3
Dec	-20.8	0	25.4	25.4
TOTAL	-2.9	463.5	379.4	-84.1

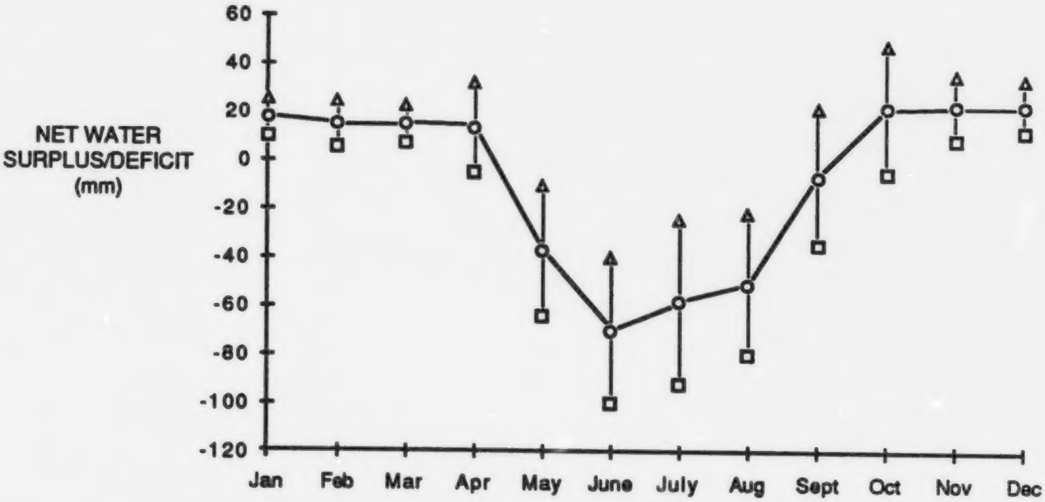
TOTAL PRECIPITATION	379 mm
POTENTIAL EVAPOTRANSPIRATION	463 mm
NET WATER BALANCE	-84 mm

* EST EVT = Estimated evapotranspiration assuming ice cover for the months of November to April inclusive.



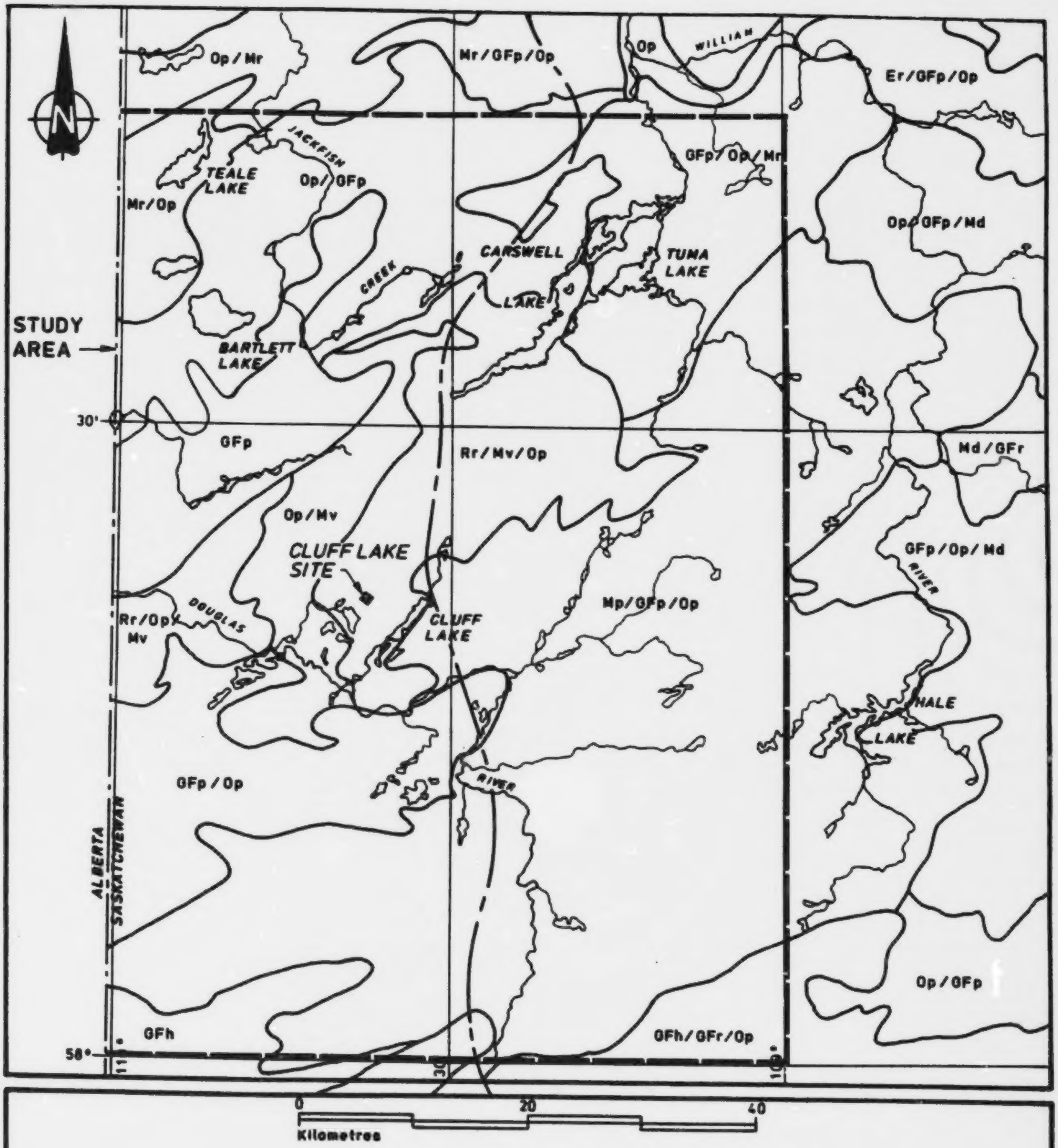
CALCULATED MEAN WATER BUDGET (1951-1980)
FOR CLUFF LAKE TAILINGS AREA

FIGURE 5-4



CALCULATED VARIATIONS IN MEAN WATER BUDGET (1951-1980)
FOR CLUFF LAKE TAILINGS AREA

FIGURE 5-5



NOTE: FOR LANDFORM DESCRIPTIONS SEE OVER

TERRAIN FEATURES - CLUFF LAKE STUDY AREA

(AFTER B.T. SCHREINER, SASK ENERGY AND MINES OPEN FILE REPORT 84-17, 1984)

FIGURE 5-6

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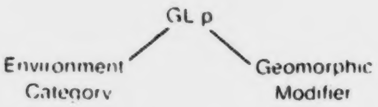
LEGEND

Terrain Classification

GEOMORPHIC MODIFIER	ENVIRONMENT CATEGORIES						
	ROCK	M MORAINAL	A ALLUVIAL	GLACIOFLUVIAL	GL GLACIO LACUSTRINE	ORGANIC	E EOLIAN
c concealed	obscured only by vegetation	——	——	——	——	——	stabilized by vegetation
w weathered	frost-broken (felsenmeer)	.... winnowed, "washed" and subdued by wave action				——	blowouts
e eroded	ice scoured	channelled by former streams of glacial meltwater, in a braided or parallel pattern				——	——
g gullied	——	.... dissected by modern ravines in a dentritic pattern					
k collapsed	karst	kettled	——	kettled	kettled	——	——
p plain	plain	plain	floodplain	outwash plain	plain	bog	plain
v veneer	——	thin enough — usually less than 3 metres thick — to reveal geomorphic fabric of underlying formation					
r ridged	corrugated with parallel stratification ridges, igneous and tectonic foliation	transverse elements end, minor moraines	point bars	eskerine complex	beach berms strandlines and wave-cut benches	string bog	dunes
h hummocky	——	ablational and chaotic disintegration moraines	——	hummocky terrain kames kettles	——	palsa	dunes
d drumlinoid	——	longitudinal elements drumlins, flutings crag and tail hills	——	——	——	——	——
t terrace	——	terrace bench	terrace bench	kame terrace	terrace bench	——	——

Example Glaciolacustrine plain



24 hours is possible for the Cluff Lake area. This would result in significant runoff. The runoff coefficients for this type of terrain are not well defined. The available studies generally do not describe runoff coefficients utilizedin various studies, however, Knight and Piesold Ltd. (1981a,b) utilized the coefficient of 0.9 in analyzing runoff in similar terrain at Key Lake.

5.3 Geology

Geomorphology

The Cluff Lake study area is dominated by three major landforms: till plains (ground moraine); glaciofluvial (outwash) plains; and, peatlands (muskeg). Eskers and kame-esker complexes, and inactive sand dunes (Schreiner, 1984) are minor landforms. Discontinuous permafrost has been identified in muskeg areas. The distribution of landforms in the vicinity of Cluff Lake is illustrated in Figure 5-6 and in detail in Figure A1 of Appendix A.

The Cluff Lake area consists of thin mineral or organic sediments overlying Precambrian age bedrock. The bedrock surface has been scoured by glaciation leaving a strong northeast-southwest trend which controls surface drainage and the distribution of landforms. Rock outcrops are common, particularly along drainage courses and on high ridges. The till sheets are thin and coarse grained. The outwash deposits are virtually devoid of silt and clay, being primarily clean sand and gravel. Some of the sandy areas have been duned, but most of the dunes are anchored by a covering of vegetation (Schreiner, 1984). Peat (muskegs) occupy most of the depressions. The deeper depressions with a significant contributing watershed area are occupied by small lakes.

Stratigraphy

Stratigraphy in the Cluff Lake study area consists of Quaternary deposits underlain by sedimentary rocks of the Athabasca Formation. Precambrian basement rocks underlie the Athabasca Formation. The Athabasca Formation is a thick, relatively flat lying succession of unmetamorphosed late Precambrian sedimentary rock which unconformably overlies the Precambrian basement. The Athabasca Formation ranges from a conglomerate at the base, to sandstone with clay and silt interbeds towards the top (Ramaekers, 1975).

Of particular interest in the Cluff Lake study area is an area where the Athabasca sediments are absent, revealing a circular area of Precambrian basement rocks. These are encircled by a ring of dolomite known as the Carswell Formation. Features within the central dome area, such as shatter cones, planar features, silt conglomerate pebbles and numerous dikes of Cluff breccia, have been considered typical of shock metamorphism, leading some to conclude that the circular structure has been generated by meteoritic impact or an underground crypto-explosion (Stearns-Roger Canada Ltd., 1976a,b). As a consequence of the formation of the Carswell structure, the rocks have been overturned so that the basement rocks are found overlying the Athabasca Formation. The basement rocks comprise granitoid, quartzofeldspathic and pelitic metasedimentary gneisses with minor iron formation and mafic and ultramafic rocks (Saskatchewan Research Council, 1982).

Glacial stratigraphy in the Cluff Lake study area consists of several till units (Schreiner, 1984). The lower till unit consists of a very sandy till containing scattered cobbles and boulders. It is grayish pink to pinkish white, and the unit is massive and moderately hard. The upper contact of this till is sharp, indicating an erosional surface. The middle till unit is similar to the lower till unit, but is more yellow. Again, the upper contact is sharp, suggesting a truncated surface. The upper till unit, commonly less than a metre thick, has a lower part which is composed of a hard, yellowish-brown, silty sand till containing numerous cobbles and pebbles but few boulders. An undulating to gradational contact separates it from the upper part which is soft, loosely packed and more sandy in texture (Schreiner, 1984).

The composition and texture of the lower till unit suggests that it is lodgement till derived from the Athabasca Group sandstone. Because its characteristics are similar, the middle unit could be a lodgement till or an ablation phase of the lower till. A distinct contact between the two units indicates that the middle till was deposited by flowing ice. The upper unit is much more mafic in composition than either of the lower units, indicating that this till was derived from Precambrian basement rocks. Again, the distinct lower contact suggests that flowing ice deposited the lower part of this unit. The soft sandy nature of the upper part of the till, and the gradational undulating contact, suggests that the upper material is an ablation till. The multiple till sequence indicates more than one glaciation in the Cluff Lake area. The different composition of the tills suggests that the ice advanced from different directions (Schreiner, 1984). Commonly, the stratum encountered in contact with the bedrock was very sandy till.

Glaciofluvial sand and gravel overlies the till in some areas. In some areas, a thin covering of silty sand, possibly eolian (wind deposited), is the surficial stratum.

In wet, low lying areas, muskeg is found. Generally, the muskeg overlies sand or silty sand.

Structure

In the vicinity of the Cluff Lake mine, till is generally thin, ranging in depth from 2 to 5 metres. Till overlies bedrock which is generally highly fractured and in places has been weathered prior to glaciation (Saskatchewan Research Council, 1982). Within bedrock troughs, glaciofluvial sands and gravel up to 10 metres in thickness may overlie the thin till strata. In some areas of glaciofluvial deposition, a sand stratum less than 0.3 m thick likely represents eolian deposition.

Muskeg deposits in poorly drained depressions vary widely in depth from less than 0.5 m to greater than 3 m (Saskatchewan Research Council, 1982).

5.4 Drainage

Cluff Lake is a headwater lake receiving local drainage at its north end by way of 5 small creeks: Beaver Creek, Boulder Creek, Earl Creek, Peter River and Claude Creek (Stearns-Roger Canada Ltd., 1976a). Cluff Lake drains south-westward into the Douglas River by way of Cluff Creek. The Douglas River flows into Lake Athabasca. A natural divide separates the Cluff Lake drainage from Carswell Lake 15 miles to the north. Carswell Lake is also a headwater lake which is drained by the William River north into Lake Athabasca.

The tailings basin for the Cluff Lake mine is in the Snake Lake watershed. This also is a low gradient headwater basin that drains to Island Lake, then through a series of small lakes to the Douglas River.

5.5 Hydrogeology

The drift and upper fractured bedrock act as one hydrostratigraphic unit. Piezometric levels in the vicinity of the Cluff Lake mine varied from near surface to as much as 10 m below existing ground surface. Generally, the water level was approximately 4 m below ground surface and followed the contours of the land. Recharge occurred in elevated areas, particularly where there were lakes or muskeg. Topographically low areas, particularly river channels, act as drains. The regional flow system is controlled both by the continuity of pervious drift units and fractured bedrock, and by regional bedrock structures. Information on the degree of structural control on the piezometric surface is very limited, but there is some evidence of artesian pressure within the bedrock.

Commenting on glacial and postglacial deposits, Meneley (no date, Volume I; Tailings Management Facility) notes that glacial eroded lineaments do not constitute a continuous, pervious seepage path for regional groundwater migration because these linear depressions produced by glacial erosion are typically filled with till and ablation detritus. In contrast, glaciofluvial sand and gravel beds deposited along glacially eroded lineaments during deglaciation are typically discontinuous and only partially fill the eroded lineament. However, it is implied that since fluvial erosion tends to produce linear, overdeepened channels within a flat valley, when filled with glaciofluvial sand and gravel they would produce a continuous, pervious path for seepage in the regional groundwater system.

The measured hydraulic conductivity in the bedrock decreases with increasing depth below the bedrock surface. Near the surface, where fractures are numerous and interconnected on a small scale, the hydraulic conductivity approaches the hydraulic conductivity of sand and gravel, approximately 10^{-4} m/sec (Meneley, no date). Measurements of the hydraulic conductivity indicate only occasional high values between the depths of 50 m and 300 m. Therefore, it was concluded that a flow continuum exists to a depth of at least 300 m. Hydraulic conductivity values used in seepage analyses ranged from 10^{-5} m/sec in the upper regions of the bedrock to 10^{-7} m/sec at 20 m to 50 m below the bedrock surface.

Numerous other tests conducted to determine the hydraulic conductivity of overburden resulted in values of approximately 10^{-4} m/sec for alluvial materials and 4×10^{-6} m/sec for till. In studies around the Claude experimental test pit (Meneley, 1982), field measurements of hydraulic conductivity resulted in values of 5.4×10^{-4} m/sec for bedrock to a depth of 2 m below the bedrock surface.

5.6 Materials Inventory

Sources of Information

Information on the Cluff Lake study area was obtained from a number of publications. A detailed listing of the source documents is given in Appendix A.

Summary of Data

Summaries of data regarding texture, structure, grain size, and permeability are found in the Table 5-2. No data were found regarding shear strength or compressibility characteristics for materials. A more comprehensive listing of data for the Cluff Lake area is given in Appendix A.

5.7 Material Characteristics

Index Properties

The majority of surficial and subsurface materials in the Cluff Lake study area are sandy or very sandy in texture. All materials tested were nonplastic, indicating an absence of clay fines.

Strength

Standard penetration tests conducted on various strata in the Cluff Lake study area are indicative of the density and bearing capacity. Sand strata varied from loose to compact while till varied from compact to very dense. Below the zone of annual freezing and desiccation, the sand strata were generally compact and the till units very dense. Shear strength tests on till reported an effective angle of internal friction of 37.5 degrees with zero cohesion

TABLE 5-2

SUMMARY OF MATERIALS, CLUFF LAKE STUDY AREA

	GRAVEL				SAND				SILT				UPPER TILL				MIDDLE TILL				LOWER TILL			
	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N
SRC DATA																								
DEPTH (m)	7.6	0.3	2.04	33.	14.9	0.1	2.3	43.	0.3	0.1	0.2	4.	4.6	0.	1.04	153.	12.2	0.5	2.36	56.	15.2	0.3	2.77	45.
THICKNESS (m)	0.3	0.2	1.78	29.	14.4	0.2	5.15	24.	0.6	0.2	0.37	4.	3.	0.	0.69	142.	7.	0.	1.09	53.	5.	0.	0.43	44.
GRADATION (% by wt.)																								
CLAY	5.	0.	0.6	32.	5.	0.	1.1	41.	5.	4.	4.5	4.	20.	0.	3.7	149.	12.	0.	3.4	56.	25.	0.	8.7	45.
SILT	7.	0.	2.2	33.	44.	0.	7.5	43.	65.	52.	58.	4.	44.	0.	13.	150.	22.	1.	9.4	56.	41.	0.	17.	45.
SAND	100.	90.	97.	33.	100.	52.	91.	43.	44.	30.	37.	4.	100.	51.	82.	150.	98.	70.	87.	56.	100.	53.	73.	45.
GRAVEL																								
MEDIAN DIAMETER (mm)	0.89	0.2	0.51	33.	0.65	0.09	0.29	43.	0.14	0.08	0.1	4.	0.6	0.14	0.28	150.	0.46	0.16	0.26	56.	0.67	0.16	0.29	45.
AMOK DATA																								
DEPTH (m)					7.6	3.	4.83	8.	9.1	9.1	9.1	2.	9.1	0.8	3.11	12.								
THICKNESS (m)					7.1	1.6	5.51	8.	1.5	1.5	1.5	1.	3.4	1.9	2.58	12.								
SPT N					20.	1.	12.	8.	13.	13.	10.	2.	100.	17.	42.	12.								
GRADATION (% by wt.)																								
CLAY					0.	0.	0.	8.	5.	2.	3.5	2.	0.	0.	0.	12.								
SILT					9.	1.	4.3	8.	60.	60.	56.	2.	31.	3.	14.	12.								
SAND					99.	91.	95.	8.	35.	48.	40.	2.	76.	32.	58.	12.								
GRAVEL					0.	0.	0.	8.	0.	0.	0.	2.	68.	6.	28.	12.								
D10 (mm)					0.15	0.08	0.11	8.	.008	.005	.007	2.	0.18	.008	0.03	12.								
D30 (mm)					0.22	0.15	0.18	8.	.022	.014	.018	2.	0.54	0.07	0.21	12.								
D60 (mm)					0.31	0.21	0.26	8.	.078	.048	.063	2.	20.	0.27	2.54	12.								
D85 (mm)					0.36	0.29	0.33	8.	0.22	0.12	0.17	2.	30.	0.6	12.9	12.								
Coef. of Uniformity					3.75	2.	2.44	8.	9.75	9.6	9.67	2.	111.	2.33	54.7	5.								
k (*10^5 m/sec)					270.	7.2	61.7	8.	2.5	2.5	2.5	2.	3600	1.	913.	8.								

(SRC data from Schreiner, 1984; Amok data from Stearns-Roger Canada Ltd., 1976 a,b)

*N = Number of tests

while the strength of sand-bentonite mixtures varied from 34.5 to 42.6 degrees (Geocon Ltd., 1981).

Compressibility

No data were found regarding the compressibility of materials in this study area.

Volume Change Characteristics

No data regarding volume change characteristics were found for the materials encountered in this study area. In general, heave associated with freezing is a potential problem where the groundwater table is near the surface in materials with greater than approximately 10 percent of grain sizes smaller than 75 um. However, the clay minerals are stable and shrinking or swelling due to changes in water content of the soil in the thawed state will be insignificant.

5.8 Mineralogy

A description of bedrock encountered in boreholes is included in the appendix to the Environmental Assessment and Safety report for Amok Ltd. (Stearns-Roger Canada Ltd., 1976b) and in Geocon Ltd. (1981). The bedrock is described as being composed of coarse to medium grained sandstone and microconglomerate. Some finer grains are found at greater depths. There is some bedding and the cement is variably siliceous, argillaceous or ferruginous. Some thin passages of pelitic silt are found.

Schreiner (1984) has divided surficial sediments into very sandy till, sandy till, silty till, and clayey till. Very sandy till is derived primarily from sediments of the Athabasca Group. Sandy till is derived from basement rocks. This till type is not found in the study area. Silty till is most common in areas such as the Cluff Lake area which is underlain by basement rocks. Its mineralogy is similar to sandy till, which reflects the bedrock source. Dominant minerals are quartz, feldspar, amphibole and other minerals derived from igeneous and metamorphic rocks. Chlorite, kaolinite, illite and possibly some micaceous minerals are also present. Some are derived directly from the bedrock while others are alteration products of minerals such as feldspars. X-ray diffractograms indicate the presence of dolomite (Saskatchewan Research Council, 1982). Proglacial sediments, mainly fluvial and lacustrine sand and gravel are similar in composition to the till, a reflection of the mineralogy of the source material. Quartz, feldspar and amphibole are the dominant minerals with chlorite, kaolinite and micas, mainly illite being the common clay minerals.

5.9 Geochemistry

Natural Water

Information regarding surface and groundwater chemistry has been reported by Meneley (1982) and Amok/Cluff Mining Ltd.'s Application for Approval for Construction of the Tailings Management Facility and Development of the "D" Ore Body (no date, Volume I and II). Surface water quality has been reported in Saskatchewan Research Council (1982). The latter is a collection of data collected during baseline studies reported in 1976, 1978 and 1979. A summary of typical water quality data is given in Table 5-3.

In general, the water in the Cluff Lake area is of the calcium and magnesium bicarbonate type. Levels of all of the other major ions are very low. Most trace elements, including heavy metals, occur in very low concentrations in the natural waters. Most trace elements were near or below the detection limits. Iron and manganese were the only metals that regularly exceeded the Saskatchewan Surface Water Quality Objectives. All radionuclides were found in very low background concentrations.

TABLE 5-3
TYPICAL SURFACE AND GROUNDWATER CHEMISTRY, CLUFF LAKE

PARAMETER	SUPFACE QUALITY	GROUNDWATER
Year	1976	
pH	7.52	7.07 +/- .46
Cond (umho/cm2)	131	
O-PO4	<0.01	.05 +/- .05
T.PO4	0.06	.19 +/- .05
TKN	0.216	.81 +/- .49
NH3	0.058	.10 +/- .08
NO3	0.001	.30 +/- .23
TDS	85	121 +/- 41
TSS	1.3	
SO4	<1	<1
CL	22	13.1 +/- 15.2
HCO3	31	70.8 +/- 24.4
CO3	0.0	-
Ca	12	16.2 +/- 9.5
Na	4.0	6.9 +/- 5.4
Mg	6	8.4 +/- 6.1
K	1.0	2.1 +/- 1.3
D. Ra226		1.2 +/- 0.7 pCi/L
T. Ra226	<0.1 pCi/l	7.0 +/- 9.3 pCi/L
U	0.0001	1.5 +/- 1.8 ug/L
Pb210	0.5 pCi/l	1.7 +/- 2.1
Po210	<0.1 pCi/l	1.4 +/- 1.3
Th230	0.001 pCi/l	-
Ag		
Al		
As	<0.001	.0007 +/- .0007
Ba	<0.02	.06 +/- .04
Bi		.004 +/- .002
Cd	<0.001	<.0005
Co	<0.001	.003 +/- .01
Cr	<0.005	.01 +/- .01
Cu	<0.001	.01 +/- .01
F		.09 +/- .05
Fe	0.25	.50 +/- .85
Hg	<0.0005	<.00005
Mn	0.01	.01 +/- .23
Mo		.01 +/- .004
Ni	0.002	.004 +/- .002
Pb	0.002	.004 +/- .003
Se	<0.005	<.001
V		.01 +/- .004
Zn	0.004	.03 +/- .04

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from W.A. Meneley Consultants Ltd., no date)

Influence of Tailings Operations

Water quality data is published by Meneley (1982). He reported that beneath the tailings pond, sulphate and chloride ions had migrated downward into the top of the sandstone from the tailings pond during the first two years of operation. The movement of Ra_{226} appears to have been retarded relative to the movement of sulphates and chlorides. It is noted that slight increases in Ra_{226} concentrations in Snake Lake are attributed to changes in the suspended material in the lakes and streams because most of the Ra_{226} in water is carried on particulate materials suspended in the water rather than being in solution. It is noted that on any subsurface seepage path from the tailings area to Snake Lake, only the dissolved heavy metals and radionuclides would migrate because the suspended material will be mechanically filtered and retained in the tailings basin. Furthermore, it stated that the migration of dissolved heavy metals and radionuclides were selectively retarded due to adsorption on fracture surfaces and particle surfaces relative to the migration rate of the major ions. A review of the water chemistry (Table 5-4) in the piezometers and toe drain sumps indicated that the radionuclide concentrations were much lower than would be expected considering the elevated sulphate and chloride concentrations. This indicated that the radionuclides were being selectively retained on fracture and particle surfaces. However, the report stated that it must be expected that, at some time in the future, Ra_{226} concentrations will increase as the retardation capacity of the natural material is overcome.

TABLE 5-4
TYPICAL WATER CHEMISTRY, CLUFF LAKE TAILINGS POND AND TOE DRAIN

		Tailings Pond 3 September 1982	Toe Drain 12 July 1982
pH		7.2	6-65
As	mg/l	<.0005	<.0005
Ba	mg/l	0.028	0.02
Bi	mg/l	0.005	0.048
Cd	mg/l	<.0005	0.002
Co	mg/l	<.001	0.031
Cr	mg/l	0.008	0.008
Cu	mg/l	0.009	0.008
Fe	mg/l	1.5	2.1
Mn	mg/l	0.45	4.8
Mo	mg/l	0.22	0.008
Ni	mg/l	0.003	0.014
Pb	mg/l	<.002	0.016
V	mg/l	0.03	0.03
Zn	mg/l	0.014	2.9
Cl*	mg/l	140	120
SO4*	mg/l	12	900
Ra 226*	Bq/l	5.5	0.01

(From Meneley, 1982)

* Estimated from graphs

5.10 Seepage Barriers

Current Barriers

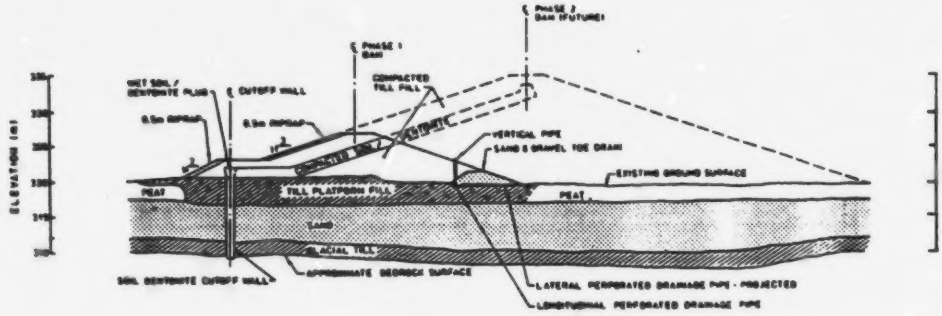
The Cluff Lake seepage barriers consist of:

- natural geologic materials including peat, till, sand and Athabasca Formation sandstone;
- a soil-bentonite slurry trench cutoff extending into the fractured Athabasca Formation bedrock; and,
- a compacted soil-bentonite cutoff constructed within the compacted till dyke.

A typical section of the containment system is shown in Figure 5-7. Glacial till, described above, was the principal construction material. Typical properties are given in Table 5-5. The till is modified for construction of the slurry trench and compacted soil-bentonite cutoff. A typical gradation curve for the till (Geocon Ltd., 1980a) is shown in Figure 5-8. The material was gap graded with a low percent of sizes in the 1.0 to 10 mm sieve size range. The natural water content of the glacial till ranged from about 3 to 10 percent. This was the primary borrow source for compacted till and soil-bentonite construction.

Natural sand and gravel was used for the toe drainage materials. The material was well graded with less than 4 percent silt and clay sizes. A typical gradation band is shown on Figure 5-8. Typical properties of the soil-bentonite mixtures and natural sand drainage blankets are given in Table 5-6.

The natural geologic materials consisted of peat up to 2.7 m in depth, which in turn was underlain by compact sand and silty sand up to 8 m thick (Geocon



NOT TO SCALE

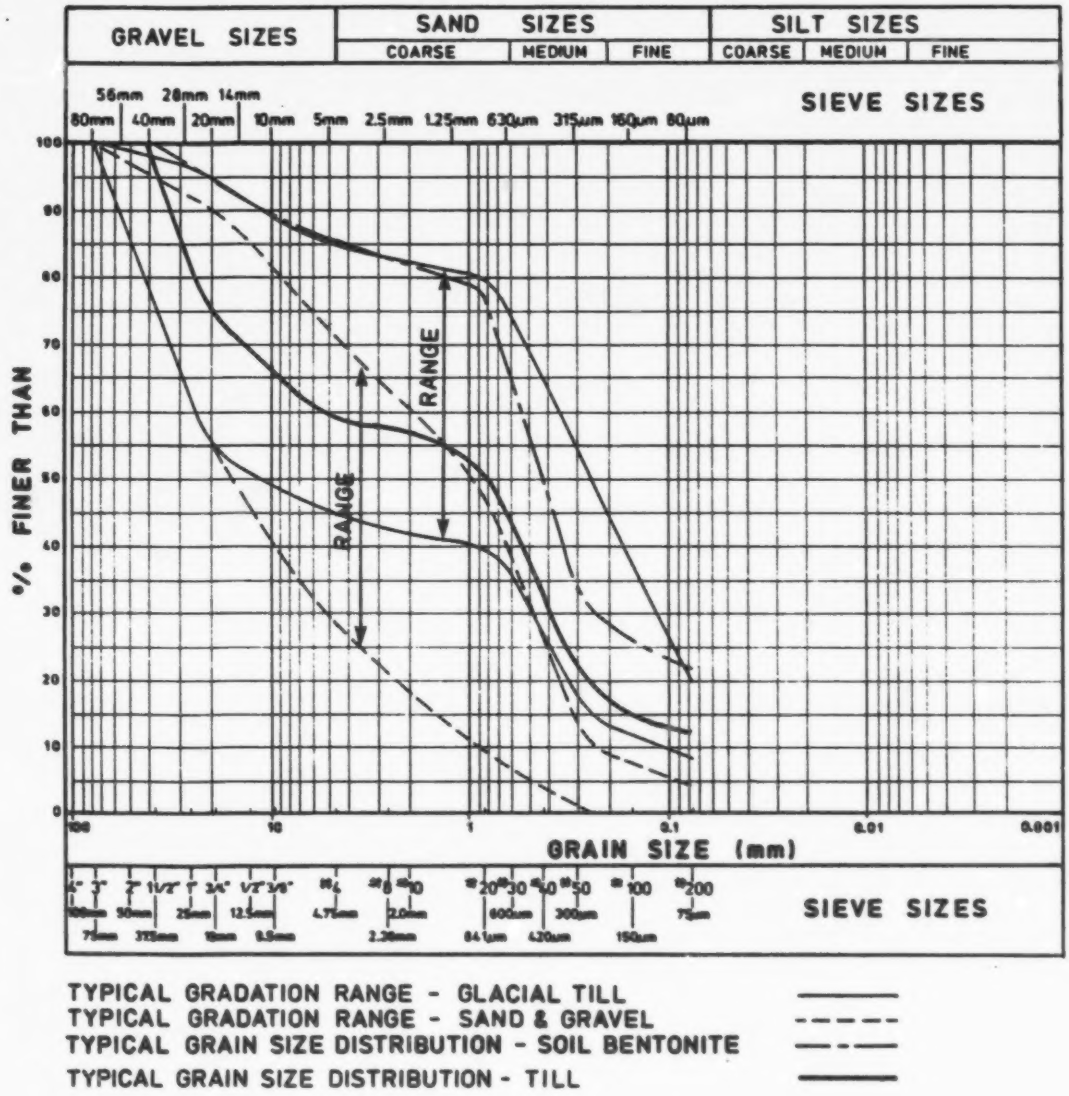
TYPICAL SECTION, CLUFF LAKE SCHEME
(FROM GEOCON LTD., 1980d)

FIGURE 5-7

TABLE 5-5
TYPICAL SOIL PROPERTIES, CLUFF LAKE

PHYSICAL PROPERTIES		SAND	TILL
GRADATION (% by weight)	Gravel	40-82	18-59
	Sand	14-60	21-74
	Silt and Clay	0-4	8-20
SPECIFIC GRAVITY		no data	2.63
IN SITU WATER CONTENT (%)		no data	8-10
ATTERBERG LIMITS	Liquid Limit (%)	NP	NP
	Plasticity Index (%)	NP	NP
COMPACTION CHARACTERISTICS (Standard Proctor)	Water content (%)	no data	9
	Dry Unit Weight (Mg/m3)	no data	2.00
EFFECTIVE SHEAR STRENGTH			
Angle of internal friction (degrees)		36.5	37.5
Cohesion (kPa)		0	0
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		no data	0.05-1.7 X 10-6
CONSOLIDATION CHARACTERISTICS			
Compression index		no data	no data
Coefficient of Consolidation (m2/y)		no data	no data

(from Geocon Ltd., 1980c, d)



TYPICAL GRAIN SIZE DISTRIBUTION - CLUFF LAKE

(FROM GEOCON LTD., 1980)

FIGURE 5-8

TABLE 5-6
PROPERTIES OF CLUFF LAKE BARRIER MATERIALS

PHYSICAL PROPERTIES		SOIL/BENTONITE SLURRY	COMPACTED SOIL/BENTONITE
GRADATION	Gravel	18	no data
(% by weight)	Sand	59	no data
	Silt and Clay	23	no data
SPECIFIC GRAVITY		1.09-1.59	2.67
IN SITU WATER CONTENT (%)		10-12	n/a
ATTERBERG LIMITS	Liquid Limit (%)	no data	no data
	Plasticity Index (%)	no data	no data
COMPACTION CHARACTERISTICS			
(Modified Proctor)	Water content (%)	n/a	9
	Dry Unit Weight (Mg/m3)	n/a	2.07
EFFECTIVE SHEAR STRENGTH			
Angle of internal friction (degrees)		no data	0 (assumed)
Cohesion (kPa)		no data	35.8-42.6
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		0.1- 3.0 X 10-9	1.2- 5.5 X 10-9
CONSOLIDATION CHARACTERISTICS			
Compression index		no data	no data
Coefficient of Consolidation (m2/y)		no data	no data

(from Geocon Ltd., 1980c, d; W.A. Meneley Consultants Ltd., 1979, 1980)

Ltd., 1980). These strata were underlain by till varying from 1.3 to 3.6 m thick which lay directly on the sandstone bedrock. A zone of permanently frozen peat and silty sand was encountered under a short section of the tailings dam.

Potential Barriers

The only potential low conductivity (less than 10^{-8} m/s) barrier materials identified in the region during this investigation were peat and silt. Minor amounts of silty lacustrine material were noted in the terrain maps but no data were available to judge the quantity or suitability; it is doubtful if it is a suitable barrier material by itself, but perhaps could be used to increase the fines content of the local tills. More information is needed to assess the feasibility of this aspect.

The peat may be suitable but only when compressed to a low void ratio; again, too few data are available to judge the feasibility of this application.

6.0 KEY LAKE AREA

6.1 Detailed Location

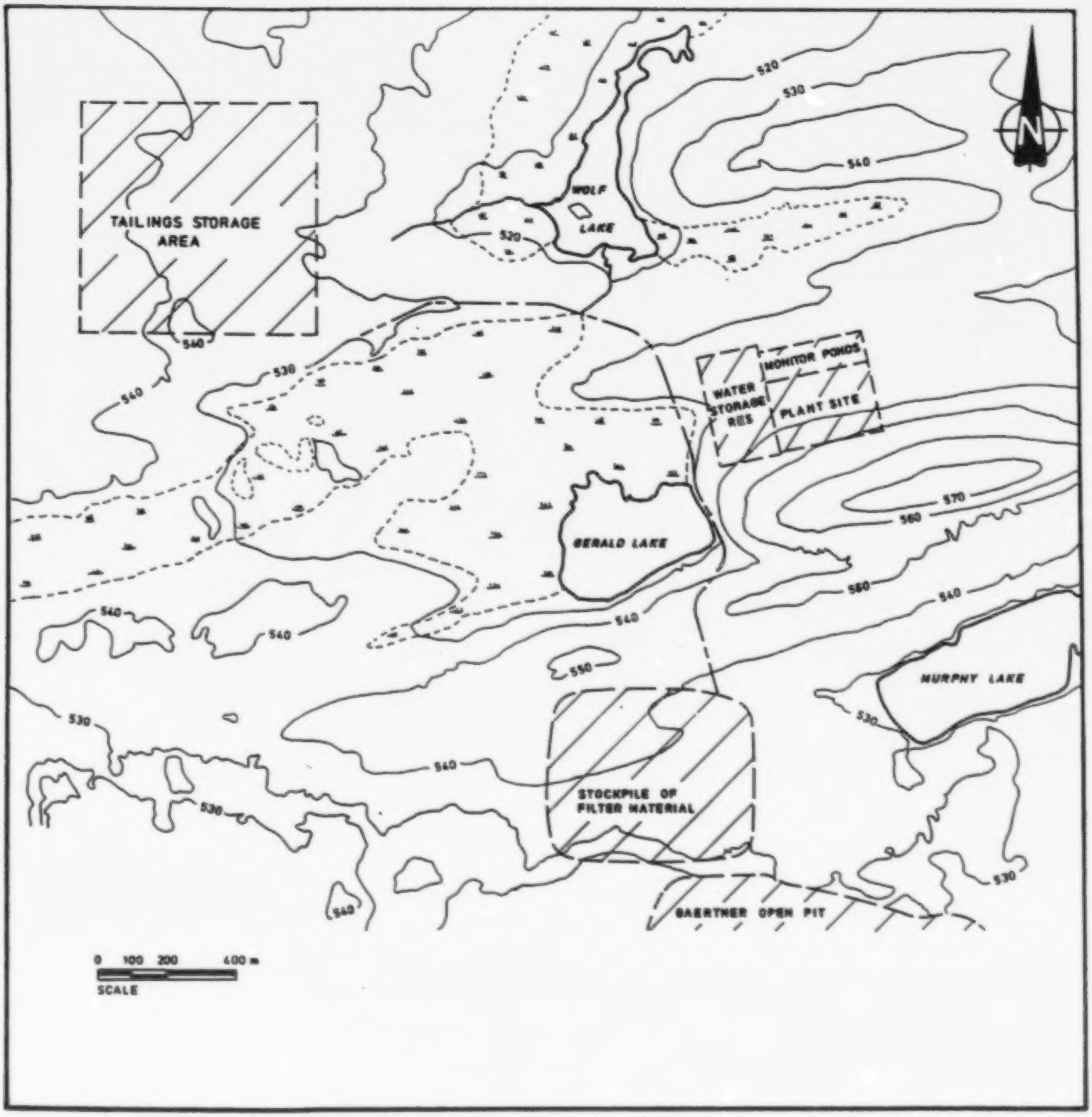
The Key Lake mine site is located immediately north of Highrock Lake in north central Saskatchewan. The map location is described as 57° 12'N latitude and 105° 40'W longitude. The detailed study area is shown in Figure 6-1.

6.2 Climate

Meteorological data for Cree Lake (Sask.) from 1951 to 1980 have been reviewed to characterize the climate of the Key Lake area of northern Saskatchewan. Key Lake is approximately 80 km east of the Cree Lake meteorological station.

The mean monthly temperature at Key Lake ranges from approximately -25° C in January to 16° C in July. Figure 6-2 shows the distribution of monthly temperatures through an average year. Based on these temperatures, the potential evapotranspiration for this region has been calculated using the Thornthwaite Method. The potential evapotranspiration is estimated to be 460 mm per year.

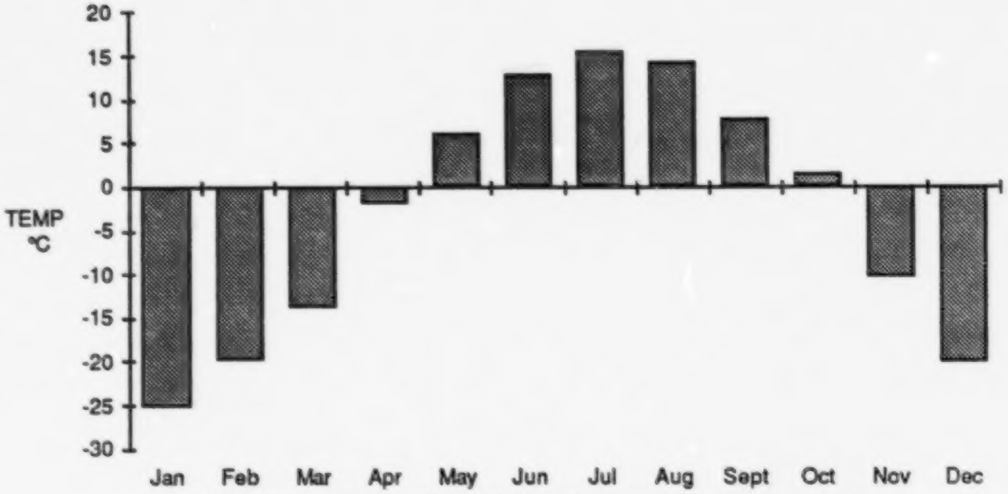
The mean annual precipitation at Key Lake is estimated to be 414 mm. The precipitation is not evenly distributed throughout the year. Generally, the colder months of October to May each receive between 13 mm and 30 mm of precipitation, mostly as snow. The summer months each receive between 50 mm and 80 mm of precipitation. The distribution of this precipitation is shown in Figure 6-3, for an average year. There is also some variation in the total precipitation from year to year. It is likely that the precipitation in the Key Lake area will range from 336 mm to 492 mm per year, for 13 out of 20 years. This range is based on one standard deviation of data about the mean value.



SITE PLAN

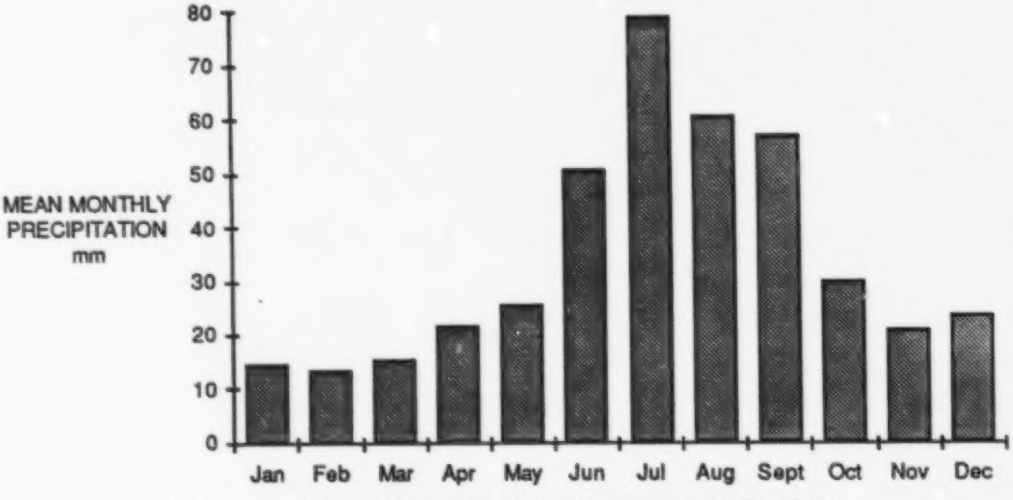
KEY LAKE TAILINGS MANAGEMENT AREA
(FROM KEY LAKE MINING CORPORATION, 1981a)

FIGURE 6-1



ESTIMATED MEAN MONTHLY TEMPERATURE (1951-1980)
FOR KEY LAKE TAILINGS AREA

FIGURE 6-2



ESTIMATED MEAN MONTHLY PRECIPITATION (1951-1980)
FOR KEY LAKE TAILINGS AREA

FIGURE 6-3

Based on an annual precipitation of 414 mm, and a potential evapotranspiration of 460 mm, there is a potential mean annual water deficit of approximately 45 mm in the Key Lake area. Monthly water balances are calculated as part of the Thornthwaite procedure (Table 6-1). Figure 6-4 shows the estimated distribution of the water balance on a monthly basis for an average year. Acknowledging the variations in annual precipitation, it is also likely that the potential annual water balance would range from a surplus of 33 mm to a deficit of 123 mm, for 13 out of 20 years. Similarly, Figure 6-5 is included to show the likely range of water balances on a monthly basis for 13 years out of 20. Because data from individual months may differ in how much they vary from the norm (and to a certain extent cancel out) one cannot simply add the monthly values shown in Figure 6-5 and consider it as "annual" data.

6.3 Geology

Geomorphology

The general distribution of landforms is shown in Figure 6-6, and in Figure B1 in Appendix B in detail. The predominant landform in the Key Lake study area is ground moraine (till plain) The till surface is drumlinoid in nature rather than hummocky. The orientation of drumlins is indicative of ice movement from northeast to southwest. Drumlins in the area may be from 500 to 2000 m in length, 300 to 1000 m in width and over 50 m high. Bayrock (1977) describes these drumlins as being constructional in origin, being composed entirely of till deposited from actively moving glaciers.

Other glacial landforms present in the area are eskers, kames and ice-walled channels. Eskers are sinuous ridges of sand and gravel deposited by ice contact streams. Most of the eskers are made up of sand with some gravel, cobbles and boulders. The eskers vary in size, and can be up to 50 m in height and range in width from tens to hundreds of metres.

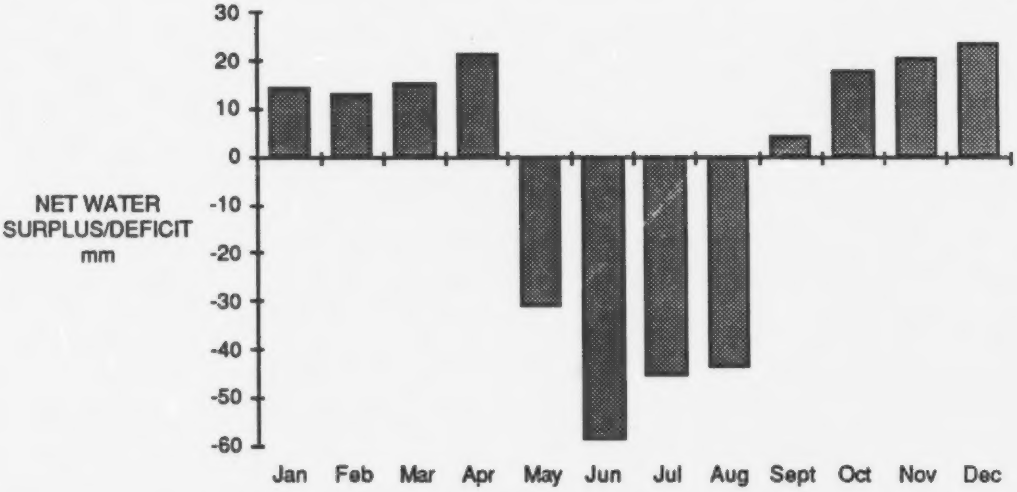
TABLE 6-1

AVERAGE WATER BUDGET CALCULATION FOR KEY LAKE TAILINGS AREA

MONTH	MEAN TEMP (C)	EST* EVT (mm)	MEAN PRECIP. (mm)	NET WATER BALANCE (mm)
Jan	-25.1	0	14.8	14.8
Feb	-19.7	0	13.4	13.4
Mar	-13.6	0	15.6	15.6
Apr	-1.8	0	21.7	21.7
May	6.1	56.7	25.8	-30.9
Jun	12.9	109.3	50.8	-58.5
Jul	15.6	124.5	79.1	-45.4
Aug	14.4	104.2	60.5	-43.7
Sept	7.9	52.6	57.3	4.7
Oct	1.6	11.9	30.1	18.2
Nov	-10.4	0	20.9	20.9
Dec	-20.1	0	23.8	23.8
TOTAL	-2.7	459.2	413.8	-45.4

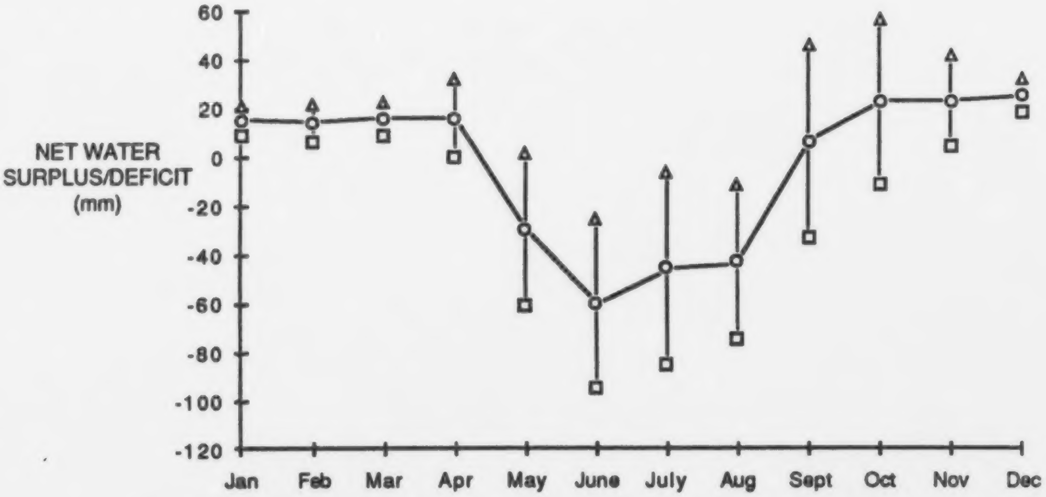
TOTAL PRECIPITATION	414 mm
POTENTIAL EVAPOTRANSPIRATION	459 mm
NET WATER BALANCE	-45 mm

* EST EVT = Estimated evapotranspiration assuming ice cover for the months of November to April inclusive.



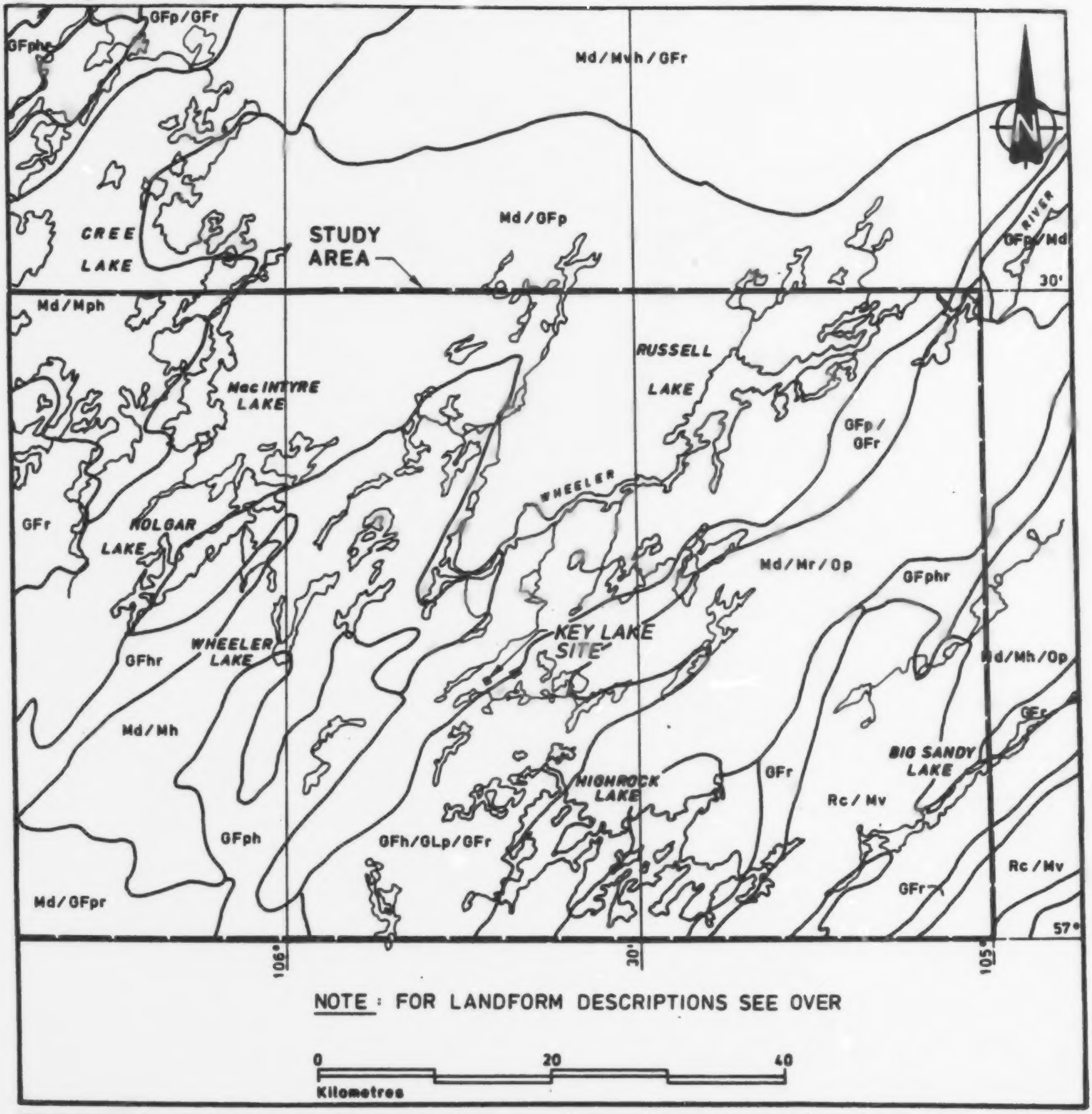
CALCULATED MEAN WATER BUDGET (1951-1980)
FOR KEY LAKE TAILINGS AREA

FIGURE 6-4



CALCULATED VARIATIONS IN MEAN WATER BUDGET (1951-1980)
FOR KEY LAKE TAILINGS AREA

FIGURE 6-5



NOTE : FOR LANDFORM DESCRIPTIONS SEE OVER

TERRAIN FEATURES - KEY LAKE STUDY AREA

(AFTER B.T. SCHREINER, SASK ENERGY AND MINES OPEN FILE REPORT 84-11, 1984)

FIGURE 6-6

LEGEND

Terrain Classification

GEOMORPHIC MODIFIER	ENVIRONMENT CATEGORIES						
	R ROCK	M MORAINAL	A ALLUVIAL	GF GLACIOFLUVIAL	GL GLACIO LACUSTRINE	O ORGANIC	E EOLIAN
c concealed	obscured only by vegetation	—	—	—	—	—	stabilized by vegetation
w weathered	frost-broken (felsenmeer)	.... winnowed, "washed" and subdued by wave action . .				—	blowouts
e eroded	ice scoured	channelled by former streams of glacial meltwater, in a braided or parallel pattern				—	—
g gullied	—	.... dissected by modern ravines in a dentritic pattern					
k collapsed	karst	kettled	—	kettled	kettled	—	—
p plain	plain	plain	floodplain	outwash plain	plain	bog	plain
v veneer	—	thin enough — usually less than 3 metres thick — to reveal geomorphic fabric of underlying formation					
r ridged	corrugated with parallel stratification ridges, igneous and tectonic foliation	transverse elements, end, minor moraines	point bars	eskerine complex	beach berms, strandlines and wave-cut benches	string bog	dunes
h hummocky	—	ablational and chaotic disintegration moraines	—	hummocky terrain kames, kettles	—	palsa	dunes
d drumlinoid	—	longitudinal elements: drumlins, flutings crag and tail hills	—	—	—	—	—
t terrace	—	terrace bench	terrace, bench	kame terrace	terrace bench	—	—

Example Glaciolacustrine plain

GL p

Environment Category — Geomorphic Modifier

An ice-walled channel is an open meltwater channel in the ice. Drift in the valley may consist of till or sand and gravel. Ice-walled channels in the Key Lake area are characterized by southwest trending bands of outwash separated by drumlinized moraine. The channel ranges in width from less than 1 kilometre to more than 5 kilometres. The depth of the channel-fill sediments varies, but may be as deep as 60 m.

Kames are glaciofluvial deposits laid down in contact with the ice. They are usually small rounded hills of irregular shape and are composed predominantly of sand and gravel. They may also contain pockets of till, large boulders and silt.

Pro-glacial landform features that occur in the Key Lake area are outwash plains. Outwash is material deposited by glacial meltwater. Sediments deposited directly in front of the glacier by meltwater contain coarse grained material. Bayrock (1977) indicates that meltwater carrying outwash followed the low ground and thus, outwash deposits are situated over bedrock depressions. In the Key Lake area, the bedrock depressions are troughlike and run in a northeast to southwest direction. The thickness of the outwash is variable; it is thickest near the center of the bedrock trough where it may be over 80 m in thickness. In general, outwash plains are stratified in structure and are composed of stratified sand and gravel. In some locations, the outwash will overlie till.

Post-glacial landforms consist of eolian features, colluvium and muskegs. Bayrock (1977) identifies some small inactive sand dunes near the northeast end of Zimmer Lake and 3.5 km. northeast of Key Lake. The sand dunes were probably formed shortly after the recession of the glacier from the area and are considered stable at the present time.

Colluvium, or slope wash is material eroded from higher slopes and deposited predominantly in depressions between drumlins or on the lower portion of slopes. Generally, the colluvium is thin and less than 1 m to 3 m thick. It generally has a finer texture than outwash or till, and does not contain gravel sizes.

Shallow, wet depressions favour the development of muskeg in the map area. Typically, the wetlands would occupy low areas between drumlins, eskers and other topographically higher features. Perched bogs are rare because of the high permeability of the drift material. Bayrock (1977) estimated that the estimates that the maximum thickness of muskegs in the Key Lake area is about 4 m. Palsas, characteristic of permanently frozen ground, are evident in some muskegs.

Stratigraphy

Stratigraphy in the Key Lake area consists of Quaternary deposits underlain by sedimentary rocks of the Athabasca Formation. Precambrian basement rocks underlie the Athabasca Formation.

The Quaternary deposits are made up of outwash plains and moraine. The Precambrian basement consists of metamorphosed, igneous, volcanic and sedimentary rocks (Schreiner, 1984).

The Athabasca group is a thick, relatively flat lying succession of unmetamorphosed late Precambrian sedimentary rock which unconformably overlies the Precambrian basement. The Athabasca group ranges from a conglomerate at the base, to sandstone with clay and silt interbeds towards the top (Raemaekers, 1975). It varies from strongly to weakly cemented and from non-hematized to deeply hematized in some portions. Faults are present in the basin which are associated with shear zones in the basement.

Glacial stratigraphy in the Key Lake area consists of a two till sequence (Schreiner, 1984). The lower till unit is very sandy and contains numerous cobbles and some large boulders. It has a grayish pink colour and is massive and moderately hard. The upper contact is very sharp, suggesting a truncated surface. The upper till unit, approximately 1 m in thickness, can be subdivided into two parts. The lowest part is composed of a moderately dense sand rich till and is pinkish gray in colour. It contains fewer cobbles than the lower till unit. The contact with the upper portion of this till is poorly defined and varies from an undulating surface to a gradational zone where no definite division can be seen. The upper material is loosely packed and rich in sand. Boulders are common and the structure appears to be massive. The yellow brown colour of this till unit is likely due to oxidation. The composition and stratigraphy suggest that the lower unit may be a lodgement till deposited by flowing ice. Rejuvenation of flow appears to have truncated the lower unit and deposited a second lodgement till. The receding ice then deposited the ablation till.

Schreiner (1984) indicates that the stratigraphic correlation of drift units in the Precambrian Shield is difficult due to the rugged terrain which provides many basins where drift units may accumulate, separated by bedrock exposures on the uplands. Thus, direct correlation of drift units over large areas is difficult. However, the homogeneity of sediments in the Athabasca group means that till derived from these sediments is generally uniform in composition. Successive glaciations eroded the same types of rocks, which resulted in multiple till units which are very similar.

Pre-glacial stratigraphy in the Key Lake area consists of stratified outwash plains. Stratified drift consisting of interbedded sand of fine to coarse texture with some silt layers is generally encountered in topographic lows associated with ice-walled channels or bedrock valleys. Here, the glaciofluvial deposits overlie bedrock or till. Post-glacial material in the Key Lake map area are restricted to peat and some localized sand dunes.

Structure

In the immediate vicinity of Key Lake, quaternary deposits are located in an erosional trough formed in the underlying Athabasca sandstone (Stevenson International Groundwater Consultants Ltd., 1978). Thicknesses of outwash material range from 75 m in the center of the trough to 0 m against the sides of bounding till ridges. A coarse sand, gravel and boulder horizon ranging up to 30 m thick lies at the bottom and along the north side of the channel. The thickness of till in lateral ridges bordering the outwash plain ranges from 10 m up to about 60 m, with the thickest till underlying the highest drumlinoid ridge just west of Murphy Lake.

6.4 Drainage

The numerous lakes in the Key Lake study area and throughout the Precambrian Shield are associated with bedrock depressions or bedrock troughs. As such, they are generally oriented parallel to the direction of ice movement, from northeast to southwest. Many bodies of water in the Key lake area are associated with kettles. Kettles are basins or depressions formed in drift deposits by the melting of buried ice blocks. They are associated with outwash, eskers, kames and other ice disintegration features. Less commonly, they are found in moraine deposits. Kettles can be a few metres to a few kilometres in width and more than 50 m deep. The kettles and bedrock depressions are drained by creeks that run parallel to bedrock structures and the direction of ice movement.

The Key lake waste management area drains into Gerald Lake, which drains into Wolf Lake, then to the Wheeler River which empties into Wollaston Lake. Both the Wheeler and Geikie River systems occupy ice marginal valleys and meltwater channels.

6.5 Hydrogeology

The surface water drainage pattern in the Key Lake area consists of interconnected lakes with channels originating at points of concentrated groundwater discharge such as lakes or muskeg (Stevenson International Groundwater Consultants Ltd., 1978). The sandy texture of the outwash materials and till, and a corresponding high permeability means that there are large flows of groundwater with little physical evidence of direct overland flow.

Groundwater moves through the surficial materials. The flow is unconfined with a hydraulic gradient parallel to the water table and land surface slope (Stevenson International Groundwater Consultants Ltd., 1978). Main aquifers in the Key Lake area correspond to bedrock troughs. Generally, water table highs correspond with topographic highs. The main aquifer identified in the Key Lake area occurred within the sand materials in the Key Lake trough.

6.6 Materials Inventory

Sources of Information

The information on the Key Lake study area was obtained from the sources outlined in Appendix B.

Primary sources of textural data were Bayrock (1977), Schreiner (1984), Ground Engineering Ltd. (1978a,b,c,d) and Clifton Associates Ltd. (1978). Permeability information was available from Knight and Peisold Ltd. (1981a,b), Stevenson International Groundwater Consultants Ltd. (1978), and Ground Engineering Ltd. (1978a,b,c,d). Geotechnical data for the outwash sand was described in Knight and Piesold Ltd. (1981a,b). All data are summarized in Table 6-2. More complete data are appended as Appendix B.

TABLE 6-2

SUMMARY OF MATERIALS, KEY LAKE STUDY AREA

	GRAVEL				SAND				SILT				UPPER TILL				MIDDLE TILL				LOWER TILL			
	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N
SRC DATA																								
DEPTH (m)	0.9	0.3	0.61	7.	50.	0.3	2.21	37.	0.9	0.6	0.67	4.	5.	0.3	0.96	31.	10.	2.	6.12	4.	4.5	4.5	4.5	1.
THICKNESS (m)	0.5	0.5	0.5	2.	60.	0.3	16.2	4.					2.	0.	0.92	5.	3.	0.	0.75	4.				1.
GRADATION (% by wt.)																								
CLAY	1.	0.	0.3	6.	7.	0.	1.2	21.	5.	1.	3.	4.	4.	0.	1.5	29.	6.	2.	3.2	4.	4.	4.	4.	1.
SILT	13.	1.	4.7	7.	39.	0.	7.8	27.	80.	51.	71.	4.	53.	5.	17.	31.	12.	8.	9.	4.	36.	36.	36.	1.
SAND	99.	86.	95.	7.	100.	54.	93.	35.	48.	15.	26.	4.	94.	46.	81.	31.	92.	82.	87.	4.	60.	60.	60.	1.
MEDIAN DIAMETER (mm)	1.2	0.27	1.6	7.	1.5	0.12	0.39	34.	0.68	0.06	0.23	4.	0.57	0.15	0.31	31.	0.41	0.23	0.35	4.	0.2	0.2	0.2	1.
CLIFTON ASSOCIATES LTD.																								
GRADATION (% by wt.)																								
SILT AND CLAY					8.	8.	8.	1.	15.	14.	14.	2.												
SAND					65.	65.	65.	1.	80.	68.	74.	2.												
GRAVEL					27.	27.	27.	1.	18.	5.	11.	2.												
GRAIN SIZES																								
D10 (mm)					0.1	0.1	0.1	1.																
D30 (mm)					0.2	0.2	0.2	1.	.2	.18	.19	2.												
D60 (mm)					0.6	0.6	0.6	1.	.5	.3	.4	2.												
D85 (mm)					80.	80.	80.	1.	12.	1.5	6.75	2.												
Coef. of Uniformity					6.	6.	6.	1.																
WATER CONTENT (%)					4.2	4.2	4.2	1.	4.2	4.	4.1	2.												
UNIT WEIGHT (kN/m^3)					18.	18.	18.	1.	18.	18.	18.	2.												
k (*10^5 m/sec)					2.7	2.7	2.7	1.	2.7	2.7	2.7	2.												
GROUND ENGINEERING LTD.	PEAT				CLAY				SAND				SILT				TILL							
DEPTH (m)	0.	0.	0.	4.	15.2	15.2	15.2	1.	12.8	1.	3.78	25.	10.1	10.1	10.1	1.	17.7	0.	5.14	21.				
THICKNESS (m)	4.4	4.3	4.32	4.	2.2	2.2	2.2	1.	6.	0.6	3.93	25.	2.7	2.7	2.7	1.	10.4	0.3	6.17	21.				
GRADATION (% by wt.)																								
SILT AND CLAY					53.	53.	53.	1.	50.	1.	15.	68.	73.	56.	62.	4.	24.	1.	8.3	24.				
SAND					39.	39.	39.	1.	99.	47.	81.	68.	44.	27.	35.	4.	95.	9.	57.	24.				
GRAVEL					8.	8.	8.	1.	43.	0.	2.8	67.	7.	0.	1.7	4.	90.	0.	33.	24.				
GRAIN SIZES																								
D10 (mm)									8.6	.75	.19	68.					4.	0.09	0.3	23.				
D30 (mm)									1.5	.76	.16	68.					22.	.095	2.28	24.				
D60 (mm)					0.23	0.23	0.23	1.	6.5	.1	.49	68.	0.91	0.09	0.09	4.	28.	0.23	5.64	23.				
D85 (mm)					2.	2.	2.	1.	28.	0.13	1.74	68.	0.27	0.11	0.2	4.	34.	0.7	12.4	22.				
Coef. of Uniformity									68.8	0.47	5.28	31.					72.7	1.87	28.3	16.				
WATER CONTENT (%)	911.	600.	756.	4.													18.	18.	18.	1.				
SPECIFIC GRAVITY	1.67	1.67	1.67	1.																				
COMPRESSION INDEX	6.8	3.8	5.8	4.																				
COEF. SECONDARY COMP.	0.02	0.02	0.02	4.																				
k (*10^5 m/sec)	.001	.001	.001	2.					15.	0.49	7.74	2.					5.8	0.88	2.69	3.				

*N = number of tests

(SRC data from Schreiner, 1984; other data from Clifton Associates Ltd., 1978; Ground Engineering Ltd., 1976)

6.7 Material Characteristics

Index Properties

As the data in Table 6-2 indicate, the majority of surficial and subsurface materials in the Key Lake area are sandy to very sandy in texture. All materials were nonplastic, consistent with the absence of clay materials.

Strength

Standard penetration values reveal the sand to be loose to medium dense and the till very dense. Knight and Piesold Ltd. (1981a,b) report direct shear tests on the outwash sand which gave angles of internal friction of 35 degrees and 38 degrees with a cohesion of zero. Samples of till compacted to modified AASHO density exhibited an angle of internal friction from 41.5 to 42.4 degrees with zero cohesion. A design value of 41.5° was used.

Compressibility

The compressibility of peat samples were evaluated by Ground Engineering Ltd. (1978a). An average value for the compressive index (C_c) was 5.6 for laboratory testing and 4.0 for a field test reported. A coefficient of secondary consolidation (C_s) of 0.25 was reported.

In general, the sandy till and outwash sand and gravel have a very stiff matrix with low compressibility.

Volume Change Characteristics

Volume change characteristics in general, are governed by the presence of clay minerals. As evidenced by the data presented in the summary tables, very few soil types are present that would potentially have volume change problems associated with heave or shrinkage. However, till in the study area generally contains more than 10 percent of grain sizes smaller than 75 um. Thus, with a high surficial water table, there is potential for frost heave caused by ice lensing.

6.8 Mineralogy

No data pertaining to the mineralogy of stratified drift or till were found. In a report by Stevenson International Groundwater Consultants Ltd. (1978) reference is made to gneissic basement rocks. It is stated that the weathered gneiss were fractured and partly altered to chlorite, kaolinite, and other clay minerals. Also, fresh basement rocks include boitite, hornblende and amphibolite gneisses, pegmatite veins and gneissic granites. In the same report, the Athabasca Formation is stated as consisting of quartzose sandstone ranging from fine to coarse grained layers with interbedded conglomerates, and consisting of clay-cemented, subround to round quartz grains of fine to coarse size. Calcite content was minor. Some sandstone was hematite stained. The drift closely reflected the mineralogy of the Athabasca Formation.

6.9 Geochemistry

Groundwater and surface water quality data were derived from a report prepared by Stevenson International Groundwater Consultants Ltd. (1978). A summary of typical data is given in Table 6-3.

Groundwater in the outwash sand, till and sandstone was neutral, with the pH ranging from 6 to 7. In the basement gneiss, the groundwater pH ranged from 7 to 8. The specific conductance of groundwater from surficial material and sandstone was less than 60 umhos/cm. The specific conductance of groundwater in gneissic rocks ranged up to 500 umhos/cm. The total dissolved solid content of groundwater in surficial material and sandstone was extremely low

TABLE 6-3
TYPICAL SURFACE AND GROUNDWATER CHEMISTRY, KEY LAKE

	SURFACE QUALITY	GROUNDWATER
Year	1977	
pH	6.90	6.50-7.31
Cond (umho/cm2)		18.0-91.0
O-PO4	0.06	0.07-0.15
T.PO4	0.07	0.07-0.15
TKN		0.20-0.40
NH3	0.02	<0.01-0.02
NO3	0.005	0.007-0.10
TDS	54.0	-
TSS	4.0	38.0-520.0
SO4	<1.0	<1.00
CL	<1.0	0.22-5.00
HCO3	8.1	10.00-51.00
CO3	0.0	NIL
Ca	0.71	<.01-0.22
Na	1.25	0.3-16.0
Mg	0.21	0.17-1.0
K	0.71	<0.1-2.5
D. Ra226	<0.1 pCi/l	<0.10 pCi/L
T. Ra226	<0.1 pCi/l	0.71 pCi/L
U	<0.0005 pCi/l	1.2-32.0
Pb210	0.10 pCi/l	
Po210	<0.1 pCi/l	1.0-14.0 pCi/L
Th230	<0.7 pCi/l	-
Ag		
Al		
As	<0.0005	0.00055-0.011
Ba	0.005	0.013-0.10
Bi		
Cd	<0.0005	0.0005-0.001
Co		<0.0001
Cr	0.017	0.009-0.024
Cu	<0.001	0.009-0.019
F	0.076	<0.01-0.01
Fe	0.042	2.29-4.43
Hg	<0.00005	<0.00005-<0.0005
Mn	0.002	0.074-0.20
Mo		
Ni	<0.001	0.005-0.320
Pb	0.003	0.010-0.021
Se	<0.002	<0.002
V	<0.01	<0.01
Zn	0.005	0.16-1.55

(from Stevenson International Groundwater Consultants Ltd., 1978)

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(less than 100 mg/L) with bicarbonates being the most common anion. Groundwater from wells penetrating bedrock had higher dissolved solid and bicarbonate contents. Most heavy metals contained in the groundwater analyzed were barely at detectable levels. However, the iron content of water in bedrock was above 3 mg/L. Radiochemical content was low in groundwater in both the surficial material and bedrock where no uranium mineralization was present. However, groundwater in or near uranium mineralization zones had radiochemical contents in excess of recommended drinking water guidelines.

Stream water was slightly acidic and had concentrations of total dissolved solids less than 50 mg/L. Where surface waters came into contact with uranium mineralization, radiochemical levels were relatively high (Seahorse Lake water). Generally, stream water drained from muskeg areas (Douglas Creek and Gerald Creek) had relatively high organic carbon content, a low pH and was coloured.

In the final safety report submitted by the Key Lake Mining Corporation (1982a), the geochemistry of seepage from the tailings and the level or retardation of arsenic, nickel, uranium, and radium were discussed. References cited in that report included Sherritt-Gordon Mines Ltd. (1979) for a seepage study; Blair et al (1980) regarding the migration of nickel due to seepage from uranium tailings at Elliot Lake; Unland (1981) regarding the migration of arsenic and nickel in groundwater; and, Taylor and Antonnaria (1979) regarding the retardation of arsenic from uranium tailings observed under actual field conditions in an overburden aquifer in central Wyoming.

Retardation capacities for uranium were assumed to be the same in till and Athabasca Formation sandstone because the natural pore fluids extracted from till and the Athabasca Formation were practically identical in chemical composition. Also, this concept was considered appropriate since the till was derived from the Athabasca Formation. Information regarding distribution coefficients, dry bulk densities and retardation factors for the various formations considered applicable to the tailings storage area are listed in Table 6-4. Migration velocities and travel times of uranium and radium 226 from the tailings storage facility to the first groundwater discharge are shown on Table 6-5.

6.10 Seepage Barriers

Current Barriers

The barriers to seepage and contaminant migration from the Key Lake tailings pond include:

- tailings;
- natural sand and gravel as a filter;
- compacted till;
- compacted soil-bentonite seals and cutoffs; and,
- natural till.

The arrangement of these materials in the tailings pond is shown in Figure 6-7, a typical section of the tailings pond embankment. A typical gradation curve for the till (Ground Engineering Ltd., 1978a,b) and outwash sand (Knight and Piesold Ltd., 1981a, 1984a) are given in Figure 6-8. Typical properties of the embankment materials are given in Table 6-6.

The natural till borrow was well graded, with from 8 to 20 percent silt and clay sizes. It was the borrow material for both compacted till and soil bentonite construction. Typical properties of the soil bentonite mixture are given in Table 6-7.

TABLE 6-4
CONTAMINANT MIGRATION DESIGN FACTORS, KEY LAKE

FORMATION	FILTER BLANKET*	UNDERSEAL	TILL	ATHABASCA FORMATION
density (g/cm3)	1.7	1.9	1.7	2.3
porosity	0.35	0.3	0.35	0.1
Kd U (cm3/g)	140	42	42	42
Kd Ra (cm3/g)	270	80	80	80
Kd Ni (cm3/g)	0	0	0	0
Kd As (cm3/g)	0	0	0	0

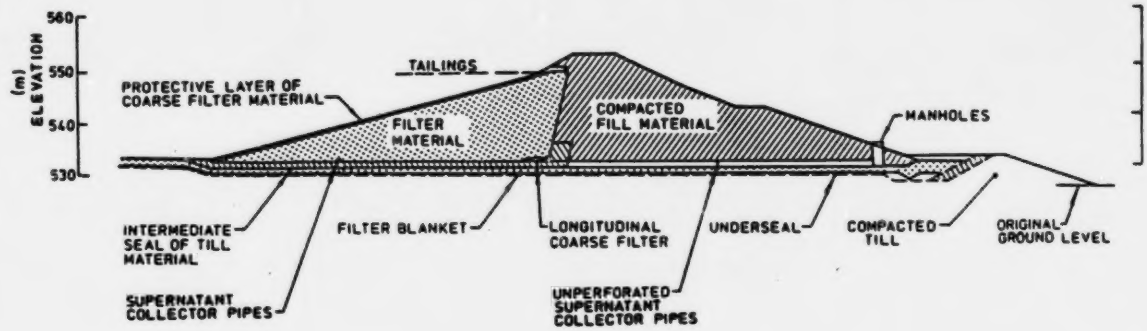
* The filter blanket values have been taken from the overburden aquifer results around the cobble ore field surrounding the Key Lake ore body.

(from Knight and Piesold Ltd., 1981)

TABLE 6-5
MIGRATION VELOCITIES AND TRAVEL TIMES

	UNDERSEAL	UNSATURATED TILL	UNSATURATED ATHABASCA FORMATION	SATURATED ATHABASCA FORMATION
Seepage Velocity (m/d)	8.9 X 10-4	0.7	4	0.36
Retardation Factor - U	226	204	966	966
Retardation Factor - Ra-226	506	388	1840	1840
Migration Velocity - U (m/d)	3.3 X 10-6	2.6 X 10-3	4.1 X 10-3	3.7 X 10-4
Migration Velocity - Ra-226 (m/d)	1.8 X 10-6	1.8 X 10-3	2.2 X 10-3	2.0 X 10-4
Length (m)	0.2	1	3	275 (min.) 925 (max.)
Travel Time Uranium	164 years	291 years	4.5 years	2,022 years (min.) 6,800 years (max.)
Travel Time Ra-226	312 years	1.5 years	3.8 years	3,851 years (min.) 12,953 years (max.)

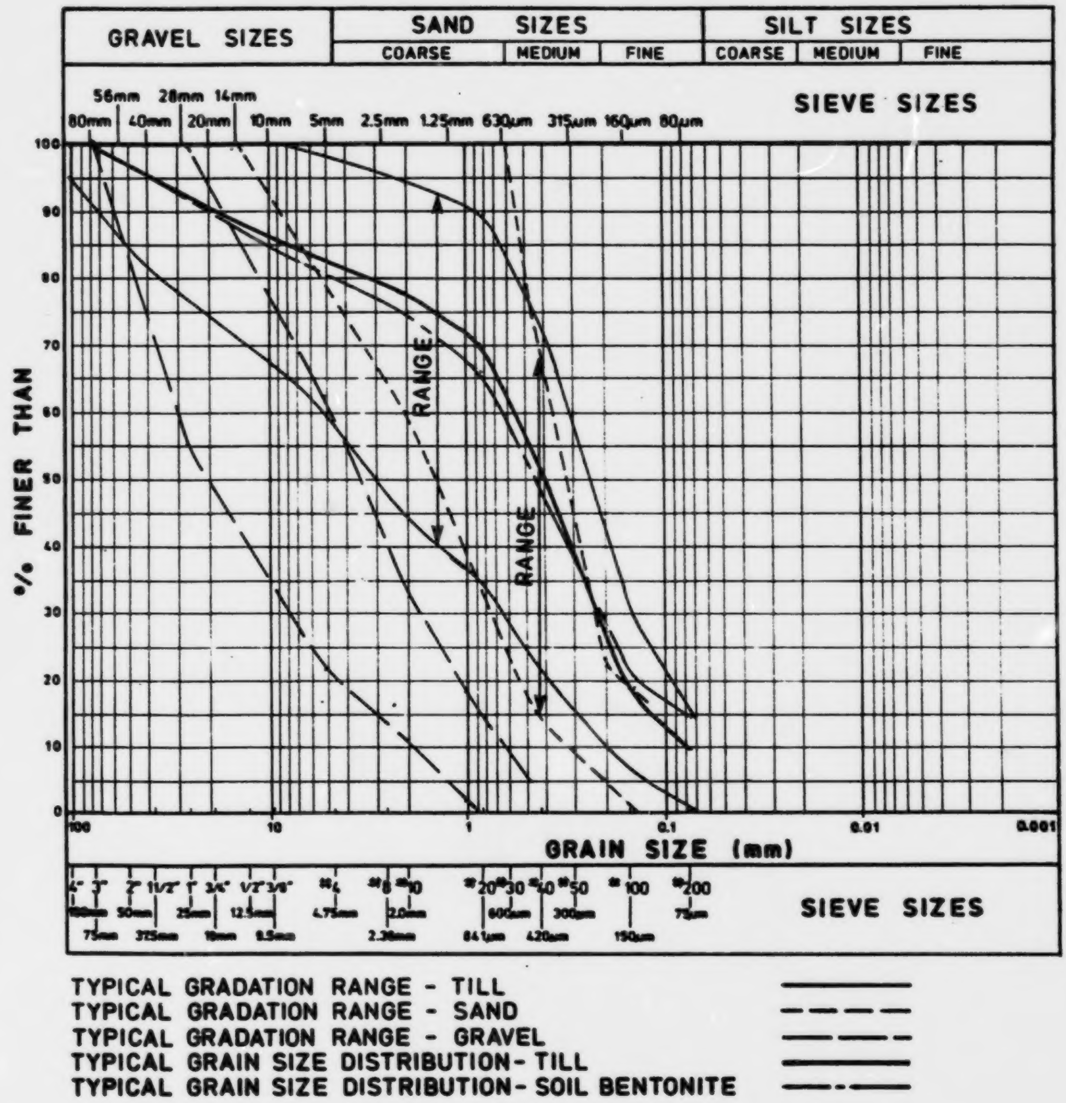
(from Knight and Piesold Ltd., 1981)


560
550
540
530
(m) ELEVATION
TAILINGS
PROTECTIVE LAYER OF COARSE FILTER MATERIAL
FILTER MATERIAL
COMPACTED FILL MATERIAL
MANHOLES
INTERMEDIATE SEAL OF TILL MATERIAL
FILTER BLANKET
LONGITUDINAL COARSE FILTER
UNDERSEAL
COMPACTED TILL
ORIGINAL GROUND LEVEL
SUPERNATANT COLLECTOR PIPES
UNPERFORATED SUPERNATANT COLLECTOR PIPES

NOT TO SCALE

TYPICAL SECTION, KEY LAKE SCHEME
(FROM KNIGHT AND PIESOLD LTD., 1981a)

FIGURE 6-7



TYPICAL GRAIN SIZE DISTRIBUTION - KEY LAKE

(FROM KNIGHT AND PIESOLD LIMITED, 1981, 1982)

FIGURE 6-8

TABLE 6-6
TYPICAL SOIL PROPERTIES, KEY LAKE MATERIALS

PHYSICAL PROPERTIES		TILL	SAND	GRAVEL
GRADATION	Gravel	21	0	71
(% by weight)	Sand	68	96	22
	Silt and Clay	11	4	<5
SPECIFIC GRAVITY		no data	no data	no data
IN SITU WATER CONTENT		8+/-	no data	no data
ATTERBERG LIMITS	Liquid Limit (%)	NP	NP	NP
	Plasticity Index (%)	NP	NP	NP
COMPACTION CHARACTERISTICS				
(Standard Proctor)	Water content (%)	8	no data	no data
	Dry Unit Weight (Mg/m3)	2.00	1.77	1.86
EFFECTIVE SHEAR STRENGTH				
Angle of internal friction (degrees)		41.5	no data	no data
Cohesion (kPa)		0	no data	no data
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		no data	.18-1.4X10-4	1x10-3
CONSOLIDATION CHARACTERISTICS				
Compression index		no data	no data	no data
Coefficient of Consolidation (m2/y)		no data	no data	no data

(from Knight and Piesold Ltd., 1981a, 1984a)

TABLE 6-7
TYPICAL SOIL PROPERTIES, KEY LAKE SOIL-BENTONITE MIX

PHYSICAL PROPERTIES		COMPACTED SOIL/BENTONITE
GRADATION	Gravel	21
(% by weight)	Sand	64
	Silt and Clay	15
SPECIFIC GRAVITY		2.59
IN SITU WATER CONTENT		8-11
ATTERBERG LIMITS	Liquid Limit (%)	no data
	Plasticity Index (%)	0-28
COMPACTION CHARACTERISTICS		
(Modified Proctor)	Water Content (%)	no data
	Dry Unit Weight (Mg/m3)	2.05
EFFECTIVE SHEAR STRENGTH		
Angle of internal friction (degrees)		no data
Cohesion (kPa)		no data
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		2.8 X 10-10
CONSOLIDATION CHARACTERISTICS		
Compression Index		no data
Coefficient of Consolidation (m2/y)		no data

(from Knight and Piesold Ltd., 1984a)

Potential Barriers

Peat and isolated pockets of lacustrine silt are the only materials identified in the study area that could be used for low permeability barriers. Insufficient data are available to judge the feasibility of using these materials. The only clay bearing material identified was kaolinized regolith but no data are available on the characteristics or quantity of material available.

7.0 MIDWEST LAKE - RABBIT LAKE AREA

7.1 Detailed Location

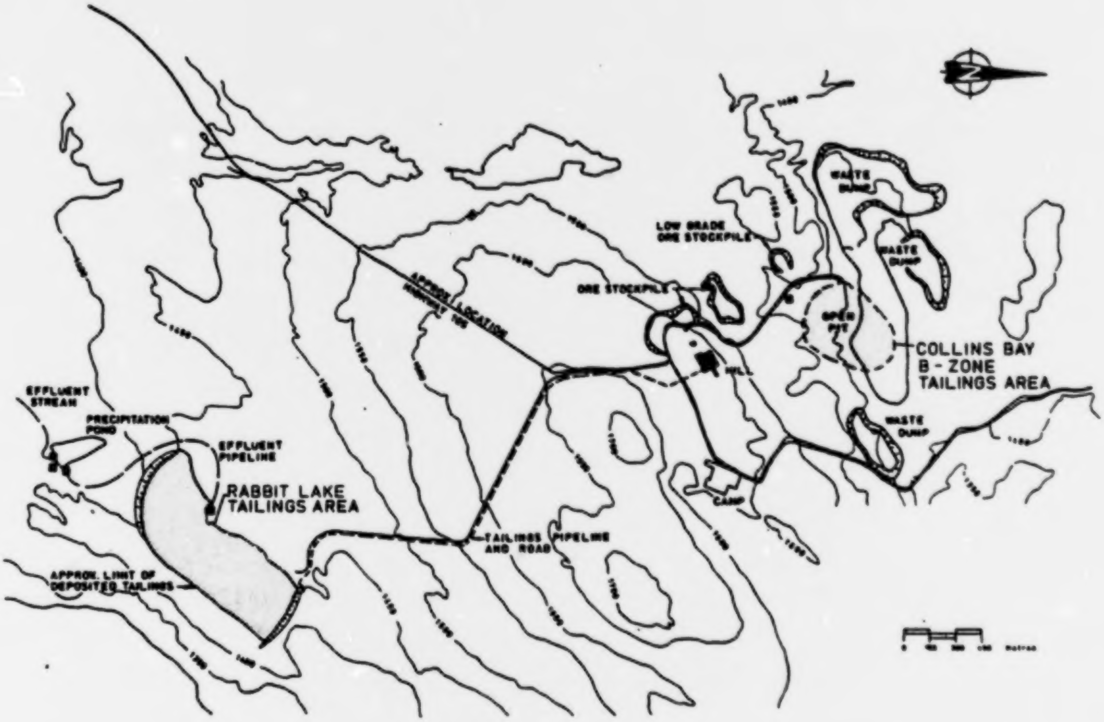
Four uranium deposits are present in this area, Rabbit Lake, Midwest Lake, Dawn Lake and Cigar Lake. A detailed location plan of the Rabbit Lake area is shown in Figure 7-1, while the other locations are shown on Figure 7-6. The Midwest Lake deposit lies beneath an arm of South McMahon Lake in Northern Saskatchewan. It is located approximately 370 km north of La Ronge, at approximately 104° 05'W, 58° 18'N, Cigar Lake is located at 104° 30'W and 58° 05'N. Dawn Lake is located at 103° 56'W and 58° 18'N. The Rabbit Lake mine is located at longitude 103° 40'W and 58° 15'N latitude.

7.2 Climate

Meteorological data for Stoney Rapids (Saskatchewan) and Brochet (Manitoba) from 1951 to 1980 have been reviewed to characterize the climate of the Midwest Lake - Rabbit Lake area of northern Saskatchewan. These lakes are between, and approximately 150 km from both these meteorological stations.

The mean monthly temperature at the Midwest Lake - Rabbit Lake area is estimated to range from -28°C in January to 15.5°C in July. Figure 7-2 shows the distribution of the monthly temperatures through an average year. Based on these temperatures, the potential evapotranspiration for this region has been calculated using the Thornthwaite Method. The potential evapotranspiration is estimated to be 432 mm per year.

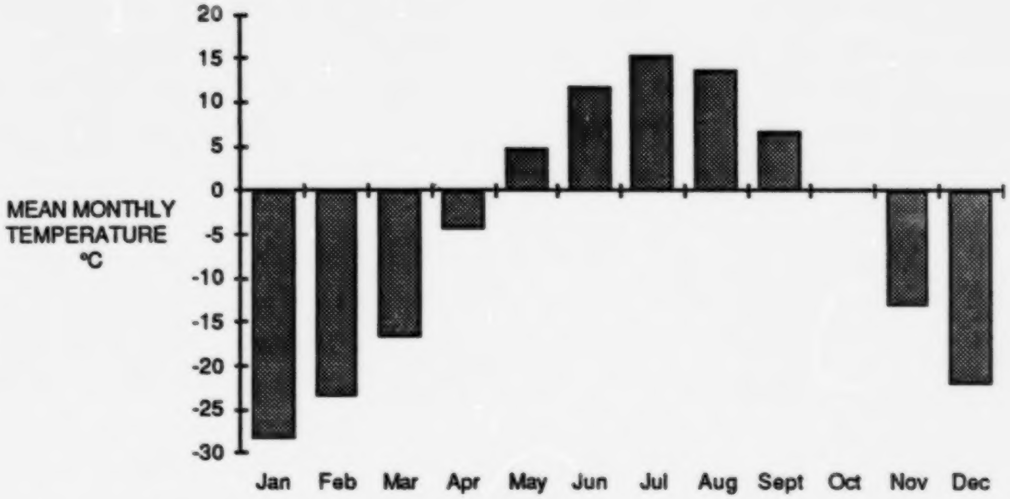
The mean annual precipitation in the Midwest Lake - Rabbit Lake area is estimated to be 402 mm. The precipitation is not evenly distributed through the year. Generally, the colder months of October to April receive between 13 mm and 33 mm of precipitation, mainly in the form of snow. The summer months receive between 50 mm and 64 mm of rainfall. The distribution of this


LOW GRADE ORE STOCKPILE
WASTE DUMP
WASTE DUMP
ORE STOCKPILE
APPROX. LOCATION HIGHWAY 105
OPEN PIT
COLLINS BAY B - ZONE TAILINGS AREA
MILL
WASTE DUMP
EFFLUENT STREAM
PRECIPITATION POND
EFFLUENT PIPELINE
RABBIT LAKE TAILINGS AREA
CAMP
TAILINGS PIPELINE AND ROAD
APPROX. LIMIT OF DEPOSITED TAILINGS

SITE PLAN

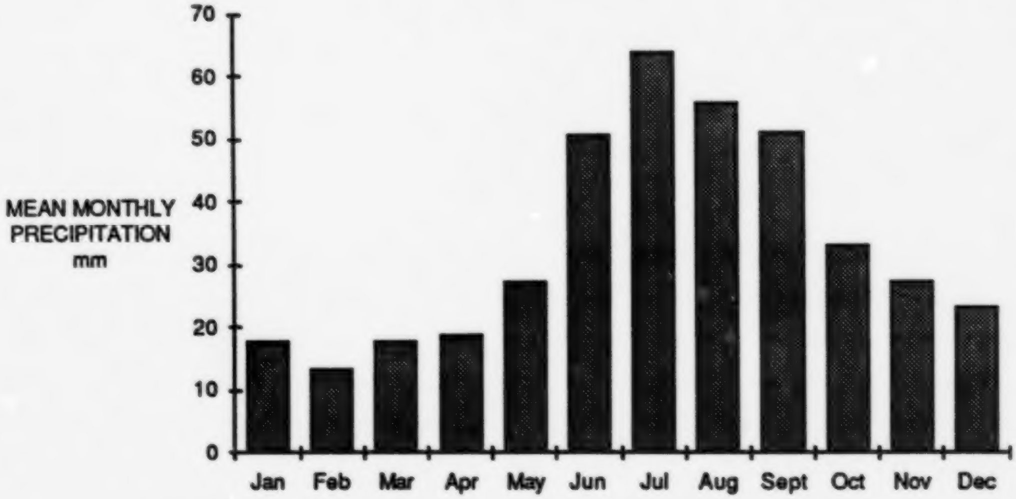
RABBIT LAKE TAILINGS MANAGEMENT AREA
(FROM MacLAREN ENGINEERS INC. 1984)

FIGURE 7-1



ESTIMATED MEAN MONTHLY TEMPERATURE (1951-1980)
FOR RABBIT LAKE

FIGURE 7-2



ESTIMATED MEAN MONTHLY PRECIPITATION (1951-1980)
FOR RABBIT LAKE TAILINGS AREA

FIGURE 7-3

precipitation is shown in Figure 7-3 for an average year. There is also some variation in the total precipitation from year to year. It is likely that the precipitation in the Midwest Lake - Rabbit Lake area will range from 316 mm to 488 mm during 13 out of 20 years. This range is based on one standard deviation of data about the mean value.

Based on an annual precipitation of 402 mm and a potential evapotranspiration of 432 mm there is an annual potential water deficit of 30 mm in the Midwest Lake - Rabbit Lake area. The variation in annual precipitation means that the potential annual water balance could range from a surplus of 56 mm to a deficit of 116 mm, for 13 years out of 20. Monthly water balances are calculated as part o the Thornthwaite procedure (Table 7-1). Figure 7-4 shows the estimated distribution of the water balance on a monthly basis for an average year. Figure 7-5 is included to show the likely ranges of water balances on a monthly basis for 13 out of 20 years. These ranges are based on one standard deviation of data about the mean value. Because the water balance data from individual months may differ in how much they vary from the norm (and to a certain extent cancel out), one cannot simply add the monthly ranges shown in Figure 7-5 and consider it an "annual" range.

7.3 Geology

Geomorphology

The distribution of landforms in the study area is shown on Figure 7-6 and Figure C1 in Appendix C. The predominant landform in the Midwest Lake - Rabbit Lake area is ground moraine. The till surface has many streamlined features, trending north-northeast, the direction from which the ice advanced. Some areas of the till plain are hummocky, and disintegrational moraine features are prominent. Much of the landscape is boulder covered, probably the erosional remnant from lacustrine erosion when the level of Wollaston Lake was much higher.

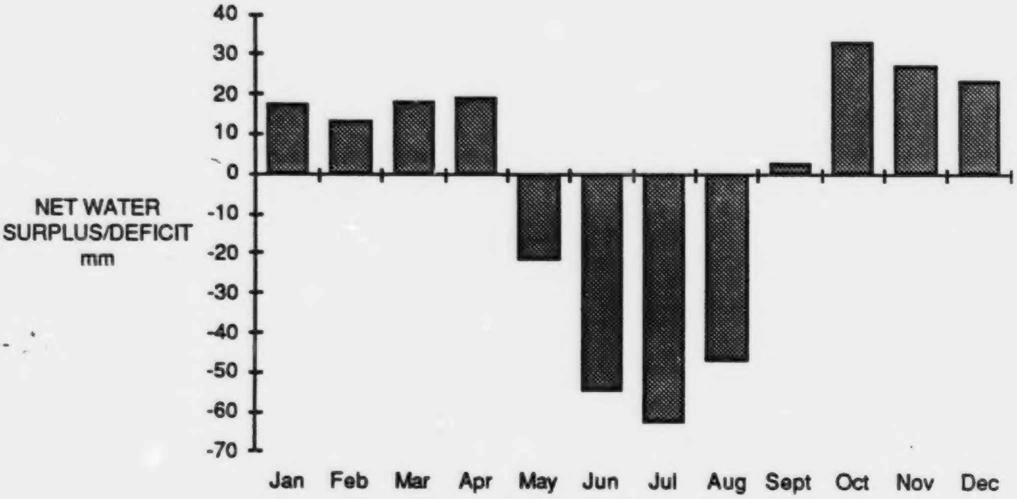
TABLE 7-1

AVERAGE WATER BUDGET CALCULATION FOR RABBIT LAKE TAILINGS AREA

MONTH	MEAN TEMP (C)	EST * EVT (mm)	MEAN PRECIP. (mm)	NET WATER BALANCE (mm)
Jan	-28.4	0	17.9	17.9
Feb	-23.5	0	13.7	13.7
Mar	-16.8	0	18.1	18.1
Apr	-4.4	0	19.1	19.1
May	4.7	48.7	27.3	-21.4
Jun	11.8	105.3	50.9	-54.4
Jul	15.5	126.7	64	-62.7
Aug	13.8	102.7	55.8	-46.9
Sept	6.7	48.2	51	2.8
Oct	-0.1	0	33.2	33.2
Nov	-13.0	0	27.4	27.4
Dec	-22.6	0	23.4	23.4
TOTAL	-4.7	431.7	401.8	-29.9

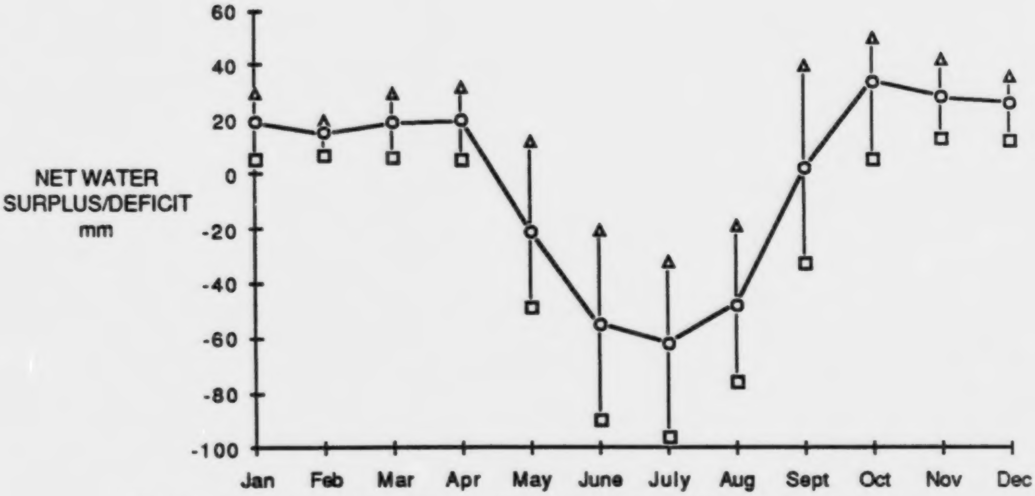
TOTAL PRECIPITATION	402 mm
POTENTIAL EVAPOTRANSPIRATION	432 mm
NET WATER BALANCE	-30 mm

* EST EVT = Estimated evapotranspiration assuming ice cover for the months November to April inclusive.



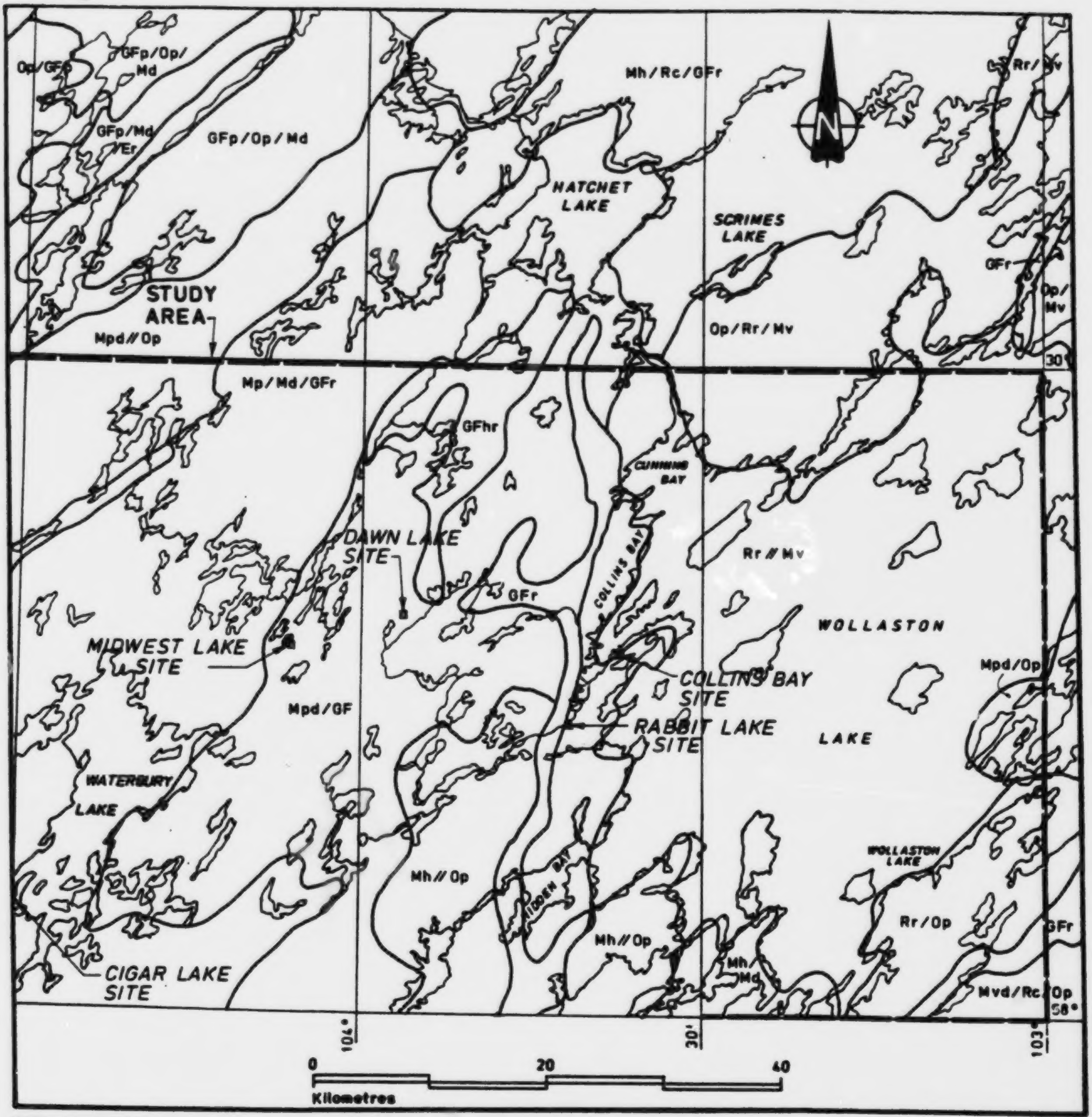
CALCULATED MEAN WATER BUDGET (1951-1980)
FOR RABBIT LAKE TAILINGS AREA

FIGURE 7-4



CALCULATED VARIATIONS IN MEAN WATER BUDGET (1951-1980)
FOR RABBIT LAKE TAILINGS AREA

FIGURE 7-5



NOTE: FOR LANDFORM DESCRIPTIONS SEE OVER

TERRAIN FEATURES
RABBIT LAKE - MIDWEST LAKE STUDY AREA

(AFTER B.T. SCHREINER, SASK ENERGY AND MINES
OPEN FILE REPORT 84-14, 1984)

FIGURE 7-6

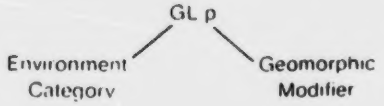
File R533
Page 98

LEGEND

Terrain Classification

GEOMORPHIC MODIFIER	ENVIRONMENT CATEGORIES						
	ROCK	M MORAINAL	A ALLUVIAL	GLACIOFLUVIAL	GL GLACIO LACUSTRINE	ORGANIC	E EOLIAN
c concealed	obscured only by vegetation	——	——	——	——	——	stabilized by vegetation
w weathered	frost-broken (felsenmeer)	.... winnowed, "washed" and subdued by wave action				——	blowouts
e eroded	ice scoured	channelled by former streams of glacial meltwater, in a braided or parallel pattern				——	——
g gullied	——	.... dissected by modern ravines in a dentritic pattern					
k collapsed	karst	kettled	——	kettled	kettled	——	——
p plain	plain	plain	floodplain	outwash plain	plain	bog	plain
v veneer	——	thin enough — usually less than 3 metres thick — to reveal geomorphic fabric of underlying formation					
r ridged	corrugated with parallel stratification ridges, igneous and tectonic foliation	transverse elements, end, minor moraines	point bars	eskerine complex	beach berms, strandlines and wave-cut benches	string bog	dunes
h hummocky	——	ablational and chaotic disintegration moraines	——	hummocky terrain kames, kettles	——	palsa	dunes
d drumlinoid	——	longitudinal elements: drumlins, flutings crag and tail hills	——	——	——	——	——
t terrace	——	terrace, bench	terrace, bench	kame terrace	terrace bench	——	——

Example Glaciolacustrine plain



Eskers and kames are prevalent. These landforms, composed mainly of sand and gravel, run in a general northeast-southwest orientation. Outwash plains are not present to the same extent as in the Key Lake area, but are evident in the northwest and southwest portions of the study area.

Organic deposits, representative of post-glacial landforms are found in poorly drained low lying areas surrounding lakes in the area. Some areas of permafrost are associated with bogs where the layers of peat, moss and other vegetation insulate the frozen ground and prevent thawing (Schreiner, 1984). Only one landform, south of the Rabbit Lake mine, has been identified as eolian in origin.

Stratigraphy

Stratigraphy in the Rabbit Lake - Midwest Lake study area consists of Quaternary deposits underlain variably by sedimentary rocks of the Athabasca Formation or Precambrian basement rocks.

The Quaternary deposits are outwash sand and till. The Precambrian basement consists of metamorphosed igneous, volcanic and sedimentary rocks (Schreiner, 1984).

The Athabasca Group sediments were previously described in Section 6.3. The study area lies on the eastern margin of the Athabasca Formation. According to Schreiner (1984), the eastern and northeastern margins of the Athabasca Formation are erosional. The Athabasca Formation consists primarily of quartz sandstones, grits, lesser conglomerates, siltstones and shales. Gulf Minerals Canada Limited (1980a) states that conglomerates occuring at the base of the Athabasca Formation at Rabbit Lake are generally underlain by a weathered zone, described as being lateritic in character.

In the vicinity of the ore deposits in the Collins Bay area, the Athabasca Formation is vividly colored, showing irregular mottling of reds, purples, browns and greens. According to Gulf Minerals Canada Limited (1980a), a feature of the zone of mineralization and the adjacent area is the presence of a great deal of clay-like material.

The Wollaston Lake basin and surrounding area was occupied by a glacial lake (Schreiner, 1984). Cobble beaches are found south of Pow Bay on the west shore of Wollaston Lake. Stratified sands occur along the Wollaston Lake road. Commonly, the shoreline of glacial Wollaston Lake was bedrock outcrop. Sediments range from fluvial sands and gravels to sandy till. Glaciolacustrine sediments are rare in this basin.

Glacial stratigraphy in the Wollaston Lake area consists of a two till sequence (Schreiner, 1984). The stratigraphy is described as a hard, massive, gray, sandy lodgement till containing abundant boulders, cobbles and pebbles, overlain by a soft, loosely consolidated, yellowish brown, sandy, ablation till. There is a distinct contact between the two units. A thin, sporadic layer of silt, probably of eolian origin, covers the upper till unit.

Within some bedrock troughs, deposits of variably sorted sand and gravel containing material derived from the Athabasca sandstone and crystalline rock formations have been found. In some areas, a thick organic layer has been deposited on top of these gravel deposits that predate the lower till. Thus, these gravel deposits have likely been deposited before or between ice advances (Gulf Minerals Canada Limited, 1980a).

The lower till in the Collins Bay area was deposited by the latest regional glaciation of northern Saskatchewan (Gulf Minerals Canada Limited, 1980a). This till has a silty to sandy matrix and is quite compact. It overlies directly the lower gravel unit where it has been preserved. Elsewhere, the lower till lies directly on the bedrock surface.

In some areas, kame-like knolls of sorted sands and gravels are found. These deposits are probably disintegration features formed during the retreat and melting of the last ice sheet.

The upper till unit is believed to be related to a minor glacial readvance (Gulf Minerals Canada Limited, 1980a). This till is composed of material derived from the Athabasca Formation. It has a very coarse texture with an erosional surface of slabs and boulders.

Recent lacustrine deposits have not been mapped on the land portions of the study area. Some lacustrine deposition has occurred within portions of Wollaston Lake. Within Collins Bay, lacustrine deposits consist of soft clay and silt resting on the upper gravel or the lower till.

Fibrous peat deposits have been mapped in the areas surrounding lakes.

Structure

Information regarding the structure of Quaternary and recent deposits has been found in Gulf Minerals Canada Limited (1980a). Lower gravels which overlie bedrock may be up to 5 m in thickness and generally occur in areas where overburden thickness exceeds 15 to 18 m. The lower till may attain thickness of 18 m. Sand and gravel deposits associated with meltwater may occur in thicknesses of up to 15 m. The upper till unit may be up to 10 m thick. Lacustrine deposits mapped in the Collins Bay area may consist of 4 m to 8 m of intermixed soft clays and silts. Peat and organics found in the study area vary in thickness from a thin veneer to a maximum of approximately 3 m.

7.4 Drainage

The numerous lakes in the Rabbit Lake - Midwest Lake study area are associated with bedrock depressions or eroded bedrock troughs. They are generally oriented from northeast to southwest, parallel to the direction of ice movement. Other lakes associates with kettles, basins or depressions formed in drift deposits by the melting of buried ice blocks.

The study area is situated in the same drainage basin as the Key Lake area. The lakes are drained by the Geikie and Wheeler River systems which flow northeast into Wollaston Lake. Wollaston Lake drains in two directions: northward in Lake Athabasca and the McKenzie River system; and, southward into Reindeer Lake and the Churchill River system.

7.5 Hydrogeology

The pervious surficial sediments and the fractured upper bedrock zone form one hydrostratigraphic unit. Groundwater levels in this surficial aquifer reflect the surface topography. In the Collins Bay area, groundwater levels in piezometers located in the high ground areas were in the range of 6 m to 9 m below ground surface indicating a recharge condition. In the lower lying areas, piezometric levels were less than 1 m below the ground surface.

A deeper groundwater flow system also exists. Piezometers installed approximately 9 to 30 m below bedrock surface in the tailings pond area indicated artesian conditions with a maximum head of 3 m above ground surface.

7.6 Material Inventory

Sources of Information

Information on the Rabbit Lake-Midwest Lake study area was obtained from the publications listed in Appendix C.

Primary sources of textural data for soils present in the study area were Schreiner (1984), Gulf Minerals Canada Limited (1980a,b,c), and Geocon Ltd. (1973).

Summary of Data

Table 7-2 presents a summary of texture, grain size, and permeability data. A summary of the standard penetration resistance is included to provide an estimate of the density and strength of the soils. Complete data are presented in Appendix C.

7.7 Material Characteristics

Index Properties

Most materials in the study area are sandy to very sandy in texture. No Atterberg limits were found for any of the materials, indicating that they are nonplastic.

Strength

No shear strength data were found for soils in the Rabbit Lake-Midwest Lake areas.

The results of standard penetration tests conducted in boreholes is indicative of strength. The sandy silt and silt encountered in the Collins Bay B-Zone

TABLE 7-2

SUMMARY OF MATERIALS, RABBIT-MIDWEST LAKE AREA

	GRAVEL				SAND				SILT				UPPER TILL				MIDDLE TILL				LOWER TILL			
	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N	MAX	MIN	AVE	N
SRC DATA																								
DEPTH (m)	2.5	0.	0.75	10.	2.5	0.3	0.88	31.	0.3	0.2	0.25	4.	6.4	0.	0.88	134.					10.6	0.	2.8	18.
THICKNESS (m)	0.3	0.	0.42	9.	1.	0.	0.11	26.	0.2	0.	0.1	4.	9.	0.	0.43	121.					8.	0.	1.97	16.
GRADATION (% by wt.)																								
CLAY	2.	0.	0.6	8.	5.	0.	1.1	28.	4.	2.	2.5	4.	16.	0.	1.8	133.					12.	0.	3.8	18.
SILT	18.	0.	3.3	8.	37.	0.	6.4	28.	65.	54.	60.	4.	74.	0.	18.	133.					67.	1.	26.	18.
SAND	100.	81.	96.	8.	100.	60.	93.	31.	44.	31.	36.	4.	100.	16.	79.	133.					98.	30.	70.	18.
MEDIAN DIAMETER (mm)	1.18	0.23	0.88	8.	0.7	0.08	0.28	31.	0.08	0.08	0.08	4.	0.97	0.14	0.37	133.					0.88	0.18	0.42	18.
COLLINS BAY	SILTY SAND				SANDY SILT				SILT				SILT AND PEAT				SILTY SAND TILL							
DEPTH (m)	3.4	3.2	3.3	2.	9.1	1.5	4.22	9.	14.6	3.7	5.56	14.	4.9	3.5	4.36	8.	12.3	0.	5.64	36.				
THICKNESS (m)	2.6	.3	1.45	2.	5.3	0.1	2.9	9.	7.5	1.2	4.08	14.	3.2	0.2	0.78	8.	15.5	1.2	6.59	36.				
SPT N	32.	32.	32.	1.	59.	1.	17.	9.	100.	16.	32.	14.	17.	1.	6.8	7.	200.	16.	72.	36.				
GRADATION (% by wt.)																								
CLAY	11.	11.	11.	1.	5.	5.	5.	2.	8.	6.	7.	6.	6.	2.	4.5	6.	14.	0.	3.5	24.				
SILT	83.	83.	83.	1.	89.	65.	77.	2.	92.	76.	88.	6.	87.	54.	72.	6.	55.	4.	22.	24.				
SAND	6.	6.	6.	1.	24.	6.	15.	2.	14.	1.	4.1	6.	40.	10.	23.	6.	76.	26.	47.	24.				
GRAVEL	0.	0.	0.	1.	3.	0.	3.	2.	2.	0.	0.3	6.	0.	0.	0.	6.	70.	6.	26.	24.				
GRAIN SIZES																								
D10 (mm)	.001	.001	.001	1.	.004	.004	.004	2.	.006	.003	.004	4.	.012	.005	.006	6.	.2	.002	.02	24.				
D30 (mm)	.009	.009	.009	1.	.012	0.01	0.01	2.	.012	.009	.01	4.	.03	.009	.029	6.	2.	0.01	.21	24.				
D60 (mm)	0.02	0.02	0.02	1.	.035	0.02	0.02	2.	.023	.02	.021	4.	.06	.033	.044	6.	30.	0.05	2.94	24.				
D85 (mm)	0.03	0.03	0.03	1.	0.5	0.04	0.27	2.	0.08	0.03	.046	4.	.14	.065	.075	6.	35.	0.25	10.3	24.				
Coef. of Uniformity	20.	20.	20.	1.	5.	5.	5.	2.	7.	3.83	5.62	4.	6.6	4.	5.18	6.	233.	0.7	61.4	24.				
k (*10^5 m/sec)					7.	8.	7.5	5.									6.	0.06	2.06	17.				

(SRC data from Schreiner, 1984; Collins Bay data from Gulf Minerals Canada Limited, 1980a,b,c; Geocon Ltd., 1973)

*N = Number of tests

development, were compact to very dense. The sand and gravelly sand were loose to very dense, while the till was commonly very dense with a few tests in the compact range.

Compressibility

No data were found regarding the compressibility of the soils.

Volume Change Characteristics

The small proportion of clay size minerals in the soils found in this study area indicate that a low swelling potential due to changes in water content exists. However, silt, sand and till with greater than 10 percent of grain sizes smaller than 75 um would be subject to frost heave where a source of water was available.

7.8 Mineralogy

No data describing the mineralogy of stratified drift material in the study area was found. The upper till in this region is composed primarily of material derived from the Athabasca Formation (Gulf Minerals Canada Limited, 1980a). As described earlier, this formation consists primarly of quartz sandstones, grits, lesser conglomerates, silt stones and shales. The lower till is largely derived from bedrock material found below the Athabasca Formation. These Aphebian age rocks are composed of pelites, sub-pelites, quartzofeldspathic gneisses, calc-silicate rocks and pegmatoids.

7.9 Geochemistry

Surface and groundwater studies were conducted for the Collins Bay B-Zone development (Gulf Minerals Canada Limited, 1980a). Chemical analyses of typical surface water and groundwater samples are listed in Table 7-3. The

TABLE 7-3
TYPICAL SURFACE AND GROUNDWATER CHEMISTRY, RABBIT LAKE

PARAMETER	SURFACE QUALITY	GROUNDWATER (Range)
Year	1978	
pH	6.67	5.90-6.50
Cond (umho/cm2)	15.70	252-465
O-PO4	<0.01	0.03-0.07
T.PO4	<0.02	0.16-0.24
TKN	0.15	0.46-16.5
NH3		0.33-5.55
NO3	0.04	0.075-0.105
TDS	30	53-425
TSS	1.4	9-862
SO4	3.04	9-18
CL	0.51	5.7-100.5
HCO3		
CO3	5.3	
Ca	2.6	3.7-27
Na	0.83	2.7-9.9
Mg	0.85	1.3-10
K	2.7	0.88-58.5
D. Ra226	nil	
T. Ra226	nil	0.6-18.6
U	0.0003	0.80-32.5
Pb210	nil	0.06-19.8
Po210	nil	<0.1-0.3
Th230	nil	
Ag	<0.01	<0.01-0.010
Al	0.19	0.07-1.76
As	<0.01	0.007-<0.01
Ba	<0.1	0.095-0.113
Bi	<0.2	0.04-0.735
Cd	<0.005	0.006-0.075
Co	<0.1	
Cr	<0.01	0.012-0.038
Cu	<0.005	0.064-0.147
F		<0.01-0.23
Fe	2.1	0.095-0.113
Hg	<0.00001	0.039-0.135
Mn	<0.03	0.36-1.17
Mo	<0.01	<0.01
Ni	<0.01	0.020-0.037
Pb	<0.01	0.033-0.113
Se	0.02	0.008-<0.01
V	<0.005	0.007-0.023
Zn	<0.005	0.024-0.91

Note: pH is reported in standard units; all other parameters are in mg/L where noted.

(from Gulf Minerals Canada Limited, 1980a)

conductivity of the water (an index of the total ions present) ranged between 18 and 32 umhos/cm^2, indicating total dissolved constituents of less than 50 mg/L.

Analysis of sediments from Collins Bay for heavy metals and potential contaminants from the ore body are summarized on Table 7-4. The Gulf Minerals Canada Limited report (1980a) indicated that sediment composition can vary greatly over relatively small geographical distances, and that elemental concentrations in sediments can be expected to principally reflect the bedrock composition of the watershed.

In a supplementary report on the disposal of tailings in the Rabbit Lake open pit contained in the Third Addendum of the Collins Bay B-Zone Development Environmental Impact Statement (Gulf Minerals Canada Limited, 1981c), commentary is provided on the hydrogeochemical reactions that would occur between radionuclides in solution and the geologic media through which they are travelling. The report states that physical-chemical reactions would take place to retard the movement of the radionuclides relative to groundwater velocity.

7.10 Seepage Barriers

Current Barriers

Seepage barriers currently utilized in the Rabbit Lake and Collins Bay tailings management schemes include:

- Natural geologic barriers comprised of local bedrock, till, peat, sand, gravel and lacustrine sediments.

- Engineered barriers consisting of compacted till, with sand filter and drainage blankets.

TABLE 7-4
SEDIMENT ANALYSIS, COLLINS BAY

Parameter	Mean Value
Ca	5.8*
Mg	2.6*
Na	12*
K	11.4*
Fe	56*
Mn	3.2*
Al	32*
Bi	1*
Mo	17
Ni	32
Zn	56
Zr	<50
Ag	<10
As	244
B	124
Ba	421
Cd	28
Cr	49
Co	21
Cu	33
Pb	160
Hg	0.233
Se	<50
V	55

* Units = mg/g, otherwise ug/g

(from Gulf Minerals Canada Limited, 1980a)

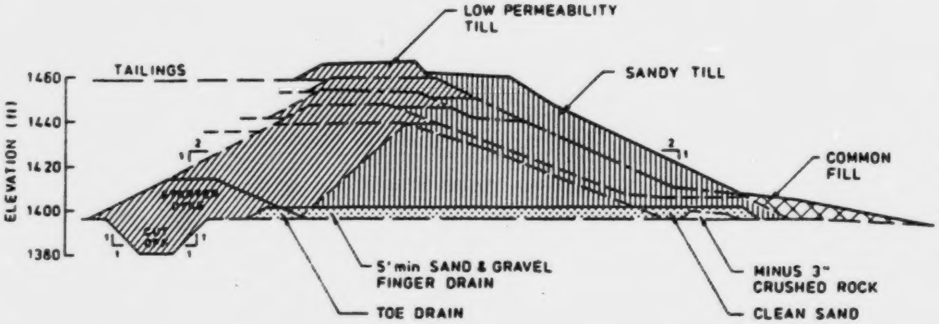
° An engineered pervious filter to isolate the tailings in the Rabbit Lake pit.

Typical sections showing how these materials are utilized are included as Figures 7-7 and 7-8. Typical gradation curves for the materials are shown in Figure 7-9. Only the compacted till used in the Rabbit Lake tailings area is of interest to this study. The properties of the materials used in construction of the Rabbit Lake scheme are given in Table 7-5.

Potential Barriers

No low permeability mineral soils were identified on land in the study area. Fine grain lacustrine silt and clay was identified in Collins Bay but no information is available on its properties, or if it is recoverable for use. Such a material may be suitable for blending with local till to improve gradation and reduce permeability.

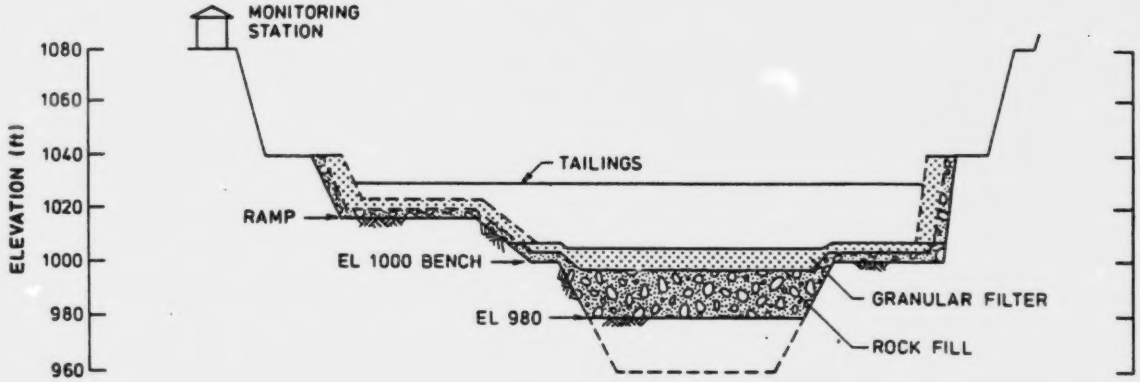
Peat is abundant in the study area. While this material compresses to form a very low permeability layer, more information is needed to assess the feasibility of its use in engineered soil barriers.



NOT TO SCALE

TYPICAL SECTION, RABBIT LAKE SCHEME
(FROM GEOCON LTD., 1980a, 1981, 1982b, 1984a)

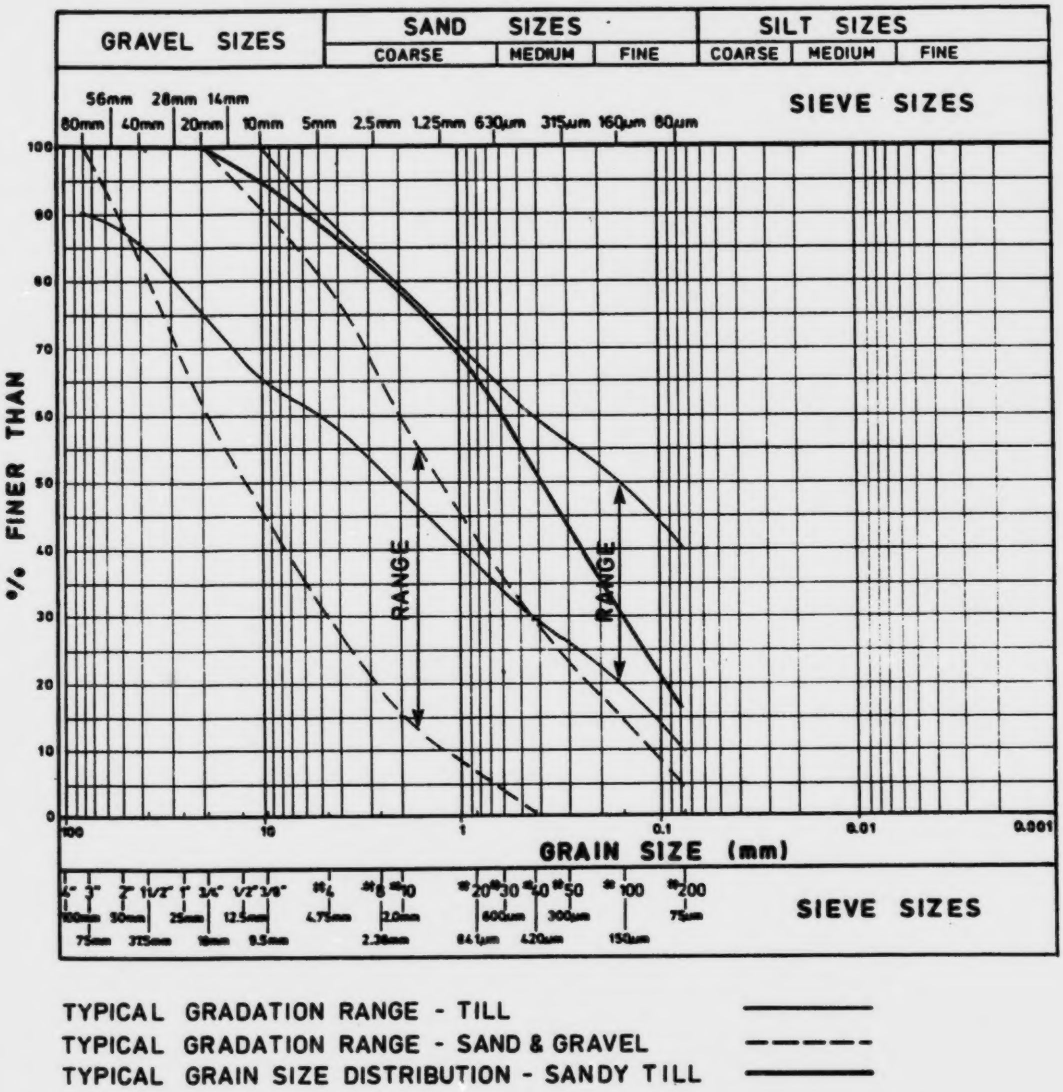
FIGURE 7-7



NOT TO SCALE

TYPICAL SECTION, COLLINS BAY SCHEME
(FROM GEOCON LTD., 1984b)

FIGURE 7-8



TYPICAL GRAIN SIZE DISTRIBUTION - RABBIT LAKE
(FROM GEOCON LTD 1973, 1982)

FIGURE 7-9

TABLE 7-5
PROPERTIES OF RABBIT LAKE EMBANKMENT MATERIALS

PHYSICAL PROPERTIES		SILTY TILL	SANDY TILL	SAND
GRADATION	Gravel	14-31	20-27	0
(% by weight)	Sand	27-61	47-66	70-100
	Silt and Clay	19-43	10-30	0-30
SPECIFIC GRAVITY		no data	no data	no data
IN SITU WATER CONTENT		no data	no data	no data
ATTERBERG LIMITS	Liquid Limit (%)	no data	no data	no data
	Plasticity Index (%)	no data	no data	no data
COMPACTION CHARACTERISTICS				
(Modified Proctor)	Water Content (%)	6.0-6.7	5.5-6.1	no data
	Dry Unit Weight (Mg/m3)	2.13-2.20	1.99-2.15	no data
EFFECTIVE SHEAR STRENGTH				
Angle of internal friction (degrees)		no data	no data	no data
Cohesion (kPa)		no data	no data	no data
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		no data	no data	no data
CONSOLIDATION CHARACTERISTICS				
Compression index		no data	no data	no data
Coefficient of Consolidation (m2/y)		no data	no data	no data

(from Geocon Ltd., 1973, 1980a, 1981, 1982b, 1984)

8.0 ELLIOT LAKE AREA

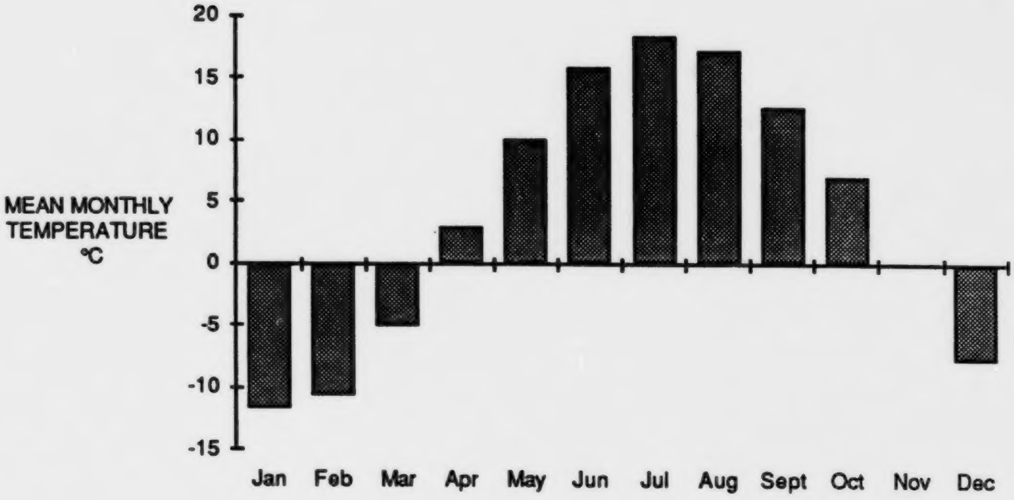
8.1 Detailed Location

As discussed in Section 2.0, there are four operating mines in the Elliot Lake mining district; the Dension Mine operated by Denison Mines Limited, and the Quirke Panel and Stanleigh mines operated by Rio Algom Limited. As shown in Figure 2-3, the mines are all within a 15 km radius of the Town of Elliot Lake, Ontario. The general map location is described approximately as 46° 30' N latitude and 82° 30' W longitude.

8.2 Climate

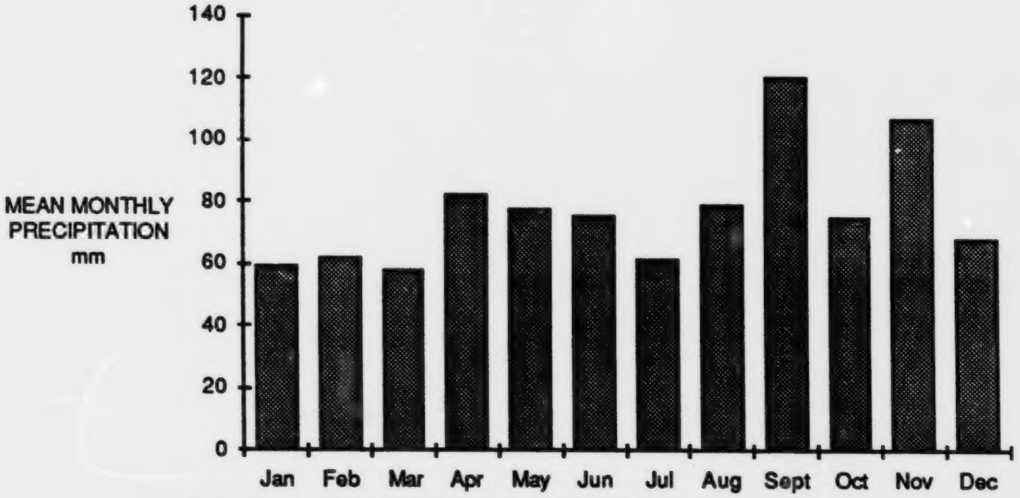
Based on climatological station data for Elliot Lake from 1951 to 1980, a water budget has been calculated using the Thornthwaite method. The mean monthly temperatures at Elliot Lake range from -11.7° C (January) to 18.4° C (July). The mean monthly temperatures are shown in Figure 8-1. The mean monthly precipitation for the area ranges from 58.3 mm (March) to 120.5 mm (September). Typically, most months have 59 to 82 mm of precipitation, except September and November during which time in excess of 110 mm may fall. The normal distribution of monthly precipitation is shown on Figure 8-2. The mean annual precipitation is approximately 926 mm. The coefficient of variation of precipitation is 0.035 which is low, relative to the other sites discussed in this report.

The potential evapotranspiration at Elliot Lake is estimated to be 542 mm/year, leaving a potential water surplus of 384 mm. The distribution of surplus water is shown on Figure 8-3 and Table 8-1. The water available for infiltration is usually less than the water surplus, depending on the topography and geology of the terrain, i.e. infiltration is reduced by the amount of surface runoff.



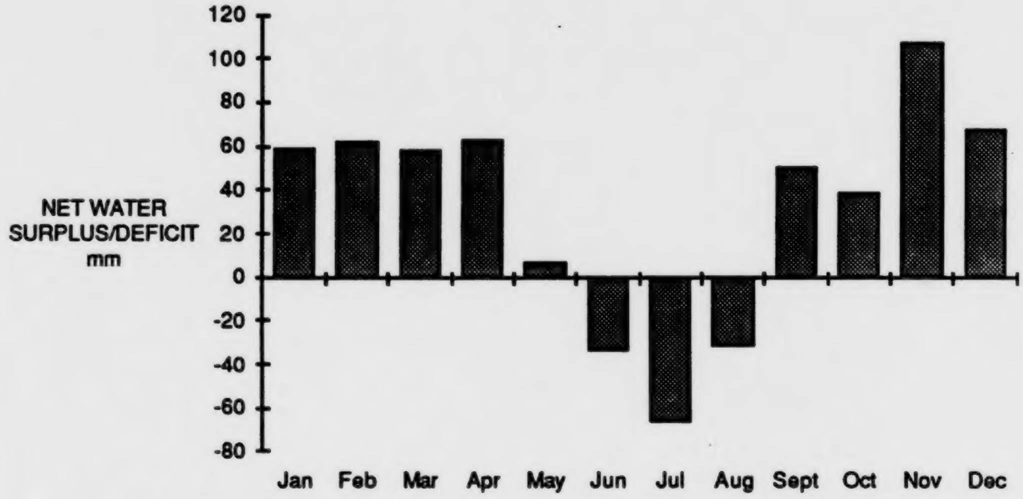
MEAN MONTHLY TEMPERATURES - ELLIOT LAKE

FIGURE 8-1



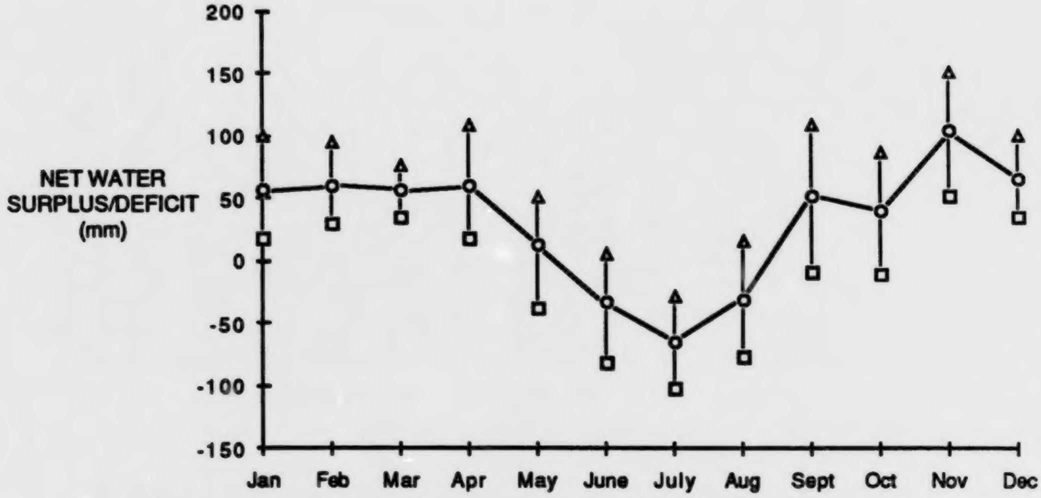
**ESTIMATED MEAN MONTHLY PRECIPITATION (1951-1980)
FOR ELLIOT LAKE**

FIGURE 8-2



CALCULATED MEAN WATER BUDGET (1951-1980) FOR ELLIOT LAKE

FIGURE 8-3



CALCULATED VARIATIONS IN MEAN WATER BUDGET (1951-1980) FOR ELLIOT LAKE

FIGURE 8-4

TABLE 8-1

AVERAGE WATER BUDGET CALCULATION FOR ELLIOT LAKE TAILINGS AREAS

MONTH	MEAN TEMP (C)	EST EVT* (mm)	MEAN PRECIP. (mm)	NET WATER BALANCE (mm)
Jan	-11.7	0	59.3	59.3
Feb	-10.6	0	62.1	62.1
Mar	-5.1	0	58.3	58.3
Apr	2.9	18.8	82.3	63.5
May	10.1	70.4	77.5	7.1
Jun	15.8	109.1	75.5	-33.6
Jul	18.4	127.8	61.7	-66.1
Aug	17.2	110.3	78.9	-31.4
Sept	12.5	69.6	120.5	50.9
Oct	7	35.8	74.9	39.1
Nov	-0.2	0	107.2	107.2
Dec	-7.7	0	68.1	68.1
TOTAL	4.1	541.8	926.3	384.5

TOTAL PRECIPITATION	926.3 mm
POTENTIAL EVAPOTRANSPIRATION	541.8 mm
NET WATER BALANCE	384.5 mm

* EST EVT = Estimated evapotranspiration assuming ice cover for the months of November to April inclusive

The variability in the potential water surplus has been calculated using the standard deviations of annual meteorological data. It is estimated that the potential water surplus would be within the range of 351 mm to 418 mm per year, for 13 out of 20 years.

Figure 8-4 is included to show the likely ranges of water balances on a monthly basis for 13 out of 20 years. These ranges are based on one standard deviation of data about the mean value. Because the water balance data from individual months may differ in how much they vary from the norm (and to a certain extent cancel out), one cannot simply add the monthly ranges shown in Figure 8-4 and consider it as the "annual" range.

8.3 Geology

Geomorphology

During the Wisconsinan Glaciation, ice advanced over the area toward the south-southwest and deposited a thin, discontinuous veneer of till over much of the bedrock surface. In a few local areas, where bedrock valleys have been infilled, the thickness of the till can be in the order of 25 m. The deposition of the till has been identified to be both ablation and lodgement in origin. The ablation tills are the more predominant in the area and usually have a silty sand texture, mixed with gravel and cobbles.

The till surface is undulating in nature expecially where the drift thickness is in excess of 1 m. Some ice-contact landforms are also present as hummocky deposits of sand, gravel and till complexes.

Other glacial age landforms identified in the area include stratified outwash sand plains and glaciolacustrine deposits of silts and clays which have been deposited during deglaciation. These deposits are commonly associated with lower lying areas between bedrock knobs and ridges, and are of limited extent and thickness. These stratified lake deposits are typically underlain by till at depth.

Since deglaciation, recent deposits, i.e. flood plain alluvium, have been deposited within the valleys of most drainage courses. Organic deposits have accumulated in many low, poorly drained depressions in the area.

The numerous lakes now present in the Elliot Lake area are associated with, and are parallel to, bedrock lineations and terminal moraines in the area. This parallel orientation is thus a reflection of the glacial ice front, from a series of stagnant ice stages extending from northwest to southeast.

Bedrock Geology

The Elliot Lake area borders the Southern and Superior provinces of the Canadian Shield. The stratigraphy of the area is therefore complex. There are three major lithologic units in this area, as identified by Robertson (1981), namely;

- Archean basement rocks;
- Huronian rocks; and,
- Post Huronian intrusive rocks.

The Archean basement complex, which is comprised of granite intrusives and meta volcanics, is overlain unconformably by an approximately 1500 to 1800 m thick sequence of sedimentary and metasedimentary rocks of Proterozoic age (MacLaren et al, 1981). This Huronian Supergroup have been folded and faulted during the Hudsonian Orogeny into an east-west synclinal structure. Throughout the Huronian Supergroup are Post-Huronian intrusive rocks, comprised of granite and diabase sills and dykes. These rocks have resulted in regional metamorphism of the sedimentary rocks.

The Proterozoic rocks are predominantly comprised of quartzites, arkoses, argillites, siltstones, minor carbonates and conglomerates.

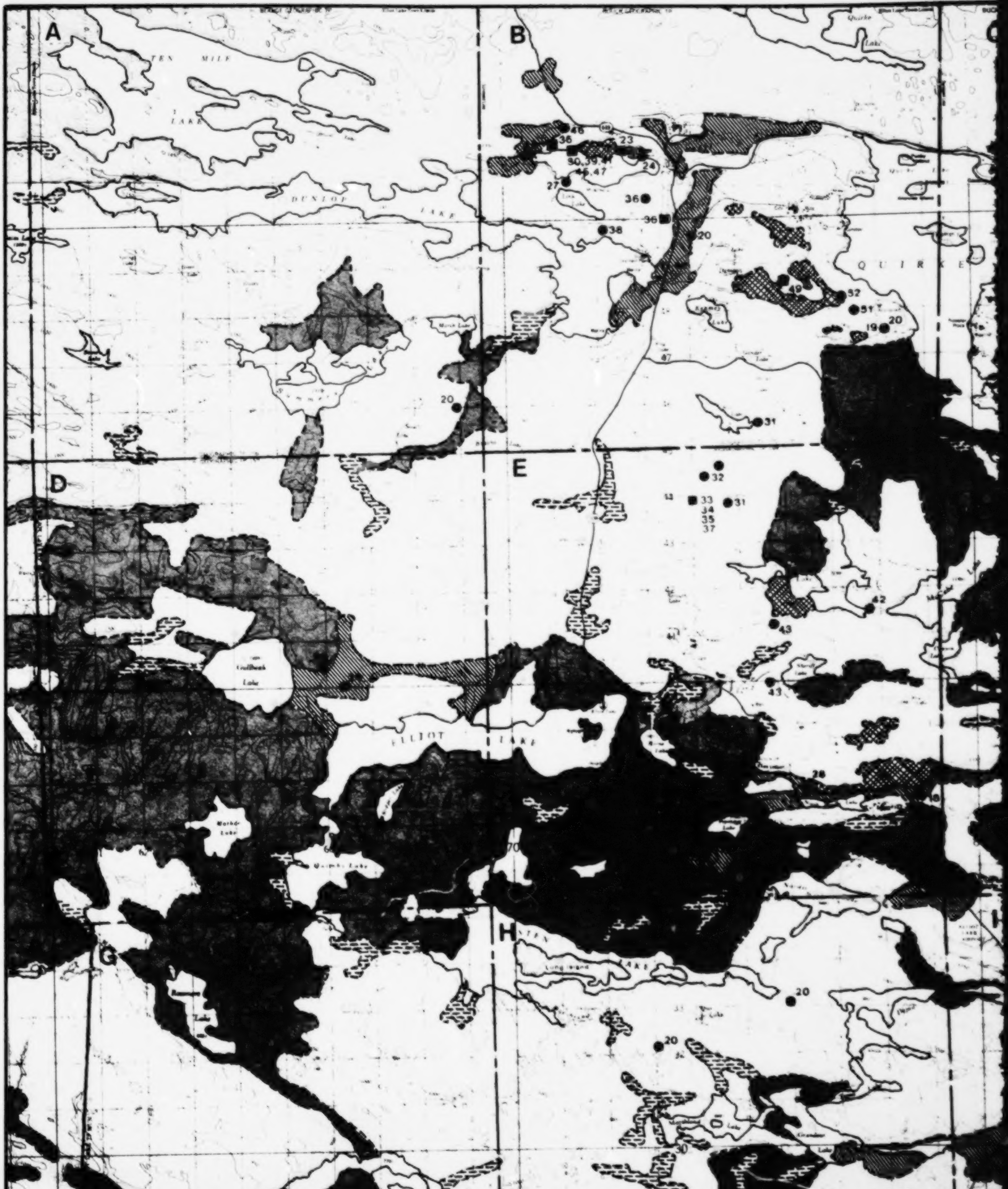
Quaternary Geology

Overlying the bedrock are thin Pleistocene deposits comprised of till overlain in many instances by glacial outwash and recent organic deposits. In the vicinity of Elliot Lake, glacial deposits are generally thin and Elliot Lake, glacial deposits are generally thin and discontinuous. However, in places where infilling of bedrock lows have taken place, drift thickness in excess of 38 m have been recorded (Ontario Geological Survey, 1984). The areal extent of the surficial deposits are shown on Figure 8-5.

In general, the organic deposits in the area are a veneer, about 1 m in thickness, and are limited in extent. The lacustrine silts on average were found to be approximately 3 m thick. The areal etent of this unit appears to be restricted to topographic lows in the immediate vicinity of the Town of Elliot Lake. The outwash sands and ice contact deposits on the other hand are more common in the Elliot Lake area. The average thickness of these units was found to be approximately 5 m. The underlying till stratum is the predominant unit in the area; its thickness ranged between 0 and 46 m, with an average of 8 m. The deeper deposits of till are generally found on the stoss side of bedrock knobs (Ontario Geological Survey, 1984).

8.4 Drainage

The surface water drainage pattern in the Elliot Lake area consists of interconnected lakes and streams, which eventually drain into the Serpent River and subsequently south into Lake Huron. From a regional point of view the Serpent River is both a local and regional discharge zone feature.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LAKE
DUNLOP
LAKE
QUIRKE
Quirke Lake
ELLIOT
LAKE
TEN
LAKE
Gullbeak Lake
Long Island
Grandeur Lake
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36
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30,39,41
46,47
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27
36
36
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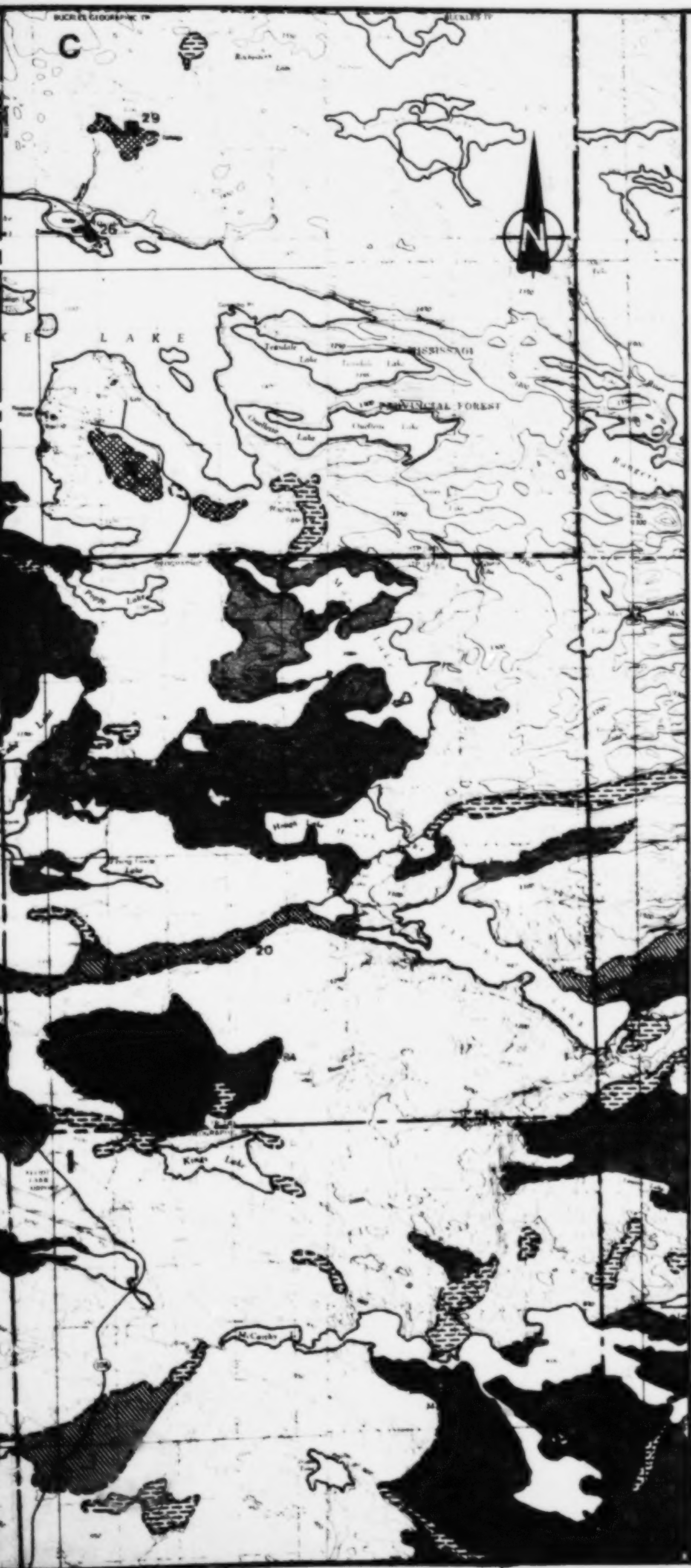
C
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26
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N
L A K E
MISSISSAGI
PROVINCIAL FOREST
Teasdale Lake
Ouellette Lake
Kings Lake
McCarthy
LEGEND
▩ Tailings
▤ Recent Alluvium & Organic Deposits
▒ Glaciolacustrine Silt
▨ Glaciofluvial Sand
▓ Till
☐ Bedrock (veneer of overburden)
● 28 Specific Reference Location & Designation
■ 33 General Reference Location & Designation
A Data Collection Area Location & Designation

FIGURE 8-5

AREAL EXTENT OF SURFACE DEPOSITS

SCALE 1 : 100.000

(AFTER VAN DINE, 1980a & 1980b)

Gartner Lee Associates Limited

8.5 Groundwater Hydrogeology

Two types of groundwater flow systems exist in the area, i.e. local flow and that of regional extent. Many small local basins are created and controlled by the bedrock topography. Within these basins the sand and gravel associated with the outwash plains, river valley terraces and alluvium are generally the best aquifers. The permeability of the granular deposits is generally in the order of 10^{-5} m/s. The glacial tills, the most predominant soil unit, are less permeable with permeabilities in the order of 10^{-7} m/s and thus often form aquitards to flow, as is the case with the lacustrine clays and silts. The lakes and rivers are local discharge areas, i.e. they receive base flow discharge from groundwater. The soils that border them are important sources of groundwater storage. The many swampy areas of the landscape also represent discharge zones and high water tables. Some of these, however, may be seasonally perched.

Flow in the bedrock is more complex and is controlled by fractures or structural discontinuities. Permeabilities in the bedrock are low except for within regional discontinuities. With depth and fewer open joints, permeabilities decrease. However, at depth, in some cases shear zones are the exception to this rule. Golder Associates (1984), stated that, based on detailed foundation investigations at tailings dams within the area, the permeability of the intact bedrock is in the order of 10^{-5} to 10^{-7}m/s near ground surface, but decreases to less than 10^{-7}m/s at a depth of 15 m below the rock surface. However, due to fracturing, the permeability of the bedrock increases close to features such as faults and dykes, with maximum permeabilities of 5 x 10^{-5} m/s close to ground surface and permeabilities of 10^{-6} to 10^{-7} m/s at a depth of 15 to 30 m below the surface of the rock.

8.6 Materials Inventory

Sources of Information

During the course of this study, a detailed review of published and available unpublished literature was carried out for purposes of characterizing the soils in the Elliot Lake study area. The main sources of data were from technical publications and unpublished consultants reports pertinent to the area.

To ensure consistency throughout the course of this study, data from each case study were summarized in the tabular form, as contained in Appendix D.

The information on the Elliot Lake study area was obtained from the publications and reports listed in Appendix D. The respective data points are shown in Figure 8-5.

Summary of Data

Data obtained from the various case histories are tabulated in Appendix D. A summary of these data is provided in Table 8-2.

8.7 Material Characteristics

The values in Table 8-2 represent the ranges and subsequent averages of data obtained from all of the case histories for the four major strata. The following descriptions are based on these averages. Also shown in Table 8-2 are the number of references used to compile the data on each of the units and each of their characteristic properties.

TABLE 8.2
SUMMARY OF MATERIALS, ELLIOT LAKE AREA

	PEAT				SILT				SAND AND GRAVEL				TILL			
	MAX	MIN	AVE	N*	MAX	MIN	AVE	N*	MAX	MIN	AVE	N*	MAX	MIN	AVE	N*
NO. OF REFERENCES				14				14				35				33
THICKNESS (m)	4	0	1.3	14	24	0.3	3.4	12	21	0.45	6.2	31	46	0.8	8.2	28
DESCRIPTION	FIBROUS SOFT, BLACK PEAT				SOFT TO V.STIFF CL SILT -SA SILT				LOOSE TO V.DENSE OUTWA SA+GR, SOME COBL+BLDR				LOOSE TO V.DENS SI, SA TILL, SOME COBL+BLDR			
SPT N	27	1	7	9	19	3	11	6	100	2	33	7	126	30	63	9
PLASTIC LIMIT (%)					22	16	19	2					12	12	12	2
LIQUID LIMIT (%)					41	25	33	2					17	14	16	2
GRADATION (% by wt.)																
CLAY					20	0	7	6	7	0	0.9	17	10	0	3	7
SILT					87	30	60	6	40	0	8	17	67	0	23	7
SAND					70	2	34	6	100	20	64	17	64	19	49	7
GRAVEL					2	0	0.3	6	76	0	28	17	65	0	25	7
GRAIN SIZES																
D10 (mm)					.040	.0007	0.02	7	0.59	0.008	0.27	17	0.02	0.002	0.008	6
D30 (mm)					.075	.001	0.03	7	8	0.05	1.2	17	0.52	0.01	0.2	6
D60 (mm)					.150	.002	0.06	7	35	0.1	6	17	2	0.035	0.8	6
D85 (mm)					.800	.007	0.2	7	100	0.2	23	17	75	0.1	2	6
Coef. of Curvature					1.4	6	0.9	7	4	0.15	1	17	107	0.008	14	6
Coef. of Uniformity					50	2	13	7	80	2.5	16	17	333	9	102	6
WATER CONTENT (% Natural)	300	47	152	5	48	25	32	5	32	11	18	7	21	10	12	10
WATER CONTENT (% Optimum)											6	1				
UNIT WEIGHT (kN/m^3)																
- in situ													21.5	20	20.3	4
- compacted											18.8	1	20.5	20	20.8	3
SPECIFIC GRAVITY									2.98	2.87	2.93	2				
POROSITY (%)											36	1				
Compression Index															0.07	1
Coef. of Consolidation															0.06	1
K SAT (X10^5m/sec)																
- in situ							10	1	10	0.1	2	10	1	9E-05	0.02	9
- compacted			.050	1											0.03	3
DEPTH TO WATER (m)	3.2	0.6	1.4	6	2.3	1.7	2	5	2.3	0.6	1.7	9	9	0.6	2.7	16

* N = number of tests

Index Properties

There are four main soil materials identified in the Elliot Lake district, namely;

- organic peat;
- silt;
- sands and gravel; and,
- till.

A common overburden relationship is comprised of gravelly sands underlain by a gravelly silty sand till. The till has a low plasticity as expected from its texture with a clay content of 3 to 10%. The silt units have a medium plasiticity (0 to 20% clay).

Strength

Standard Penetration resistance values and stratigraphic descriptions recorded for the various strata generally indicate that the peat unit was soft to firm, the silt was stiff, the sand was compact and the till was very dense.

Golder, 1980, reported the minimum angle of shearing resistance in the sand and gravel unit was 32°.

Compressibility

As indicated on Table 8-2, only one compression index C_c was recorded for any of the surficial deposits. A value 0.07 was reported for a single test result of the till.

Permeability

The average coefficients of permeability for the various strata from various reports were:

Peat $k = 5 \times 10^{-7}$ m/s*
Silt $k = 10^{-4}$ m/s
Sand $k = 2 \times 10^{-5}$ m/s
Till $k = 2 \times 10^{-7}$ m/s
* compressed sample

Volume Change Characteristics

Volume change characteristics related to moisture content variations are governed by the presence of active clay minerals. As indicated by the data presented in the summary table, very few soils in the area would potentially have volume change problems due to heave or shrinkage. However, most of the units, due to their high silt-fine sand content, could be frost susceptible.

8.8 Mineralogy

The sands and tills in the area have been mapped by the Ontario Institute of Pedology as non-calcareous. Work done by Dave et al (1982) suggests, however, that there are trace amounts of carbonate minerals in the sand. The presence of these minerals has effectively retarded acid-front advance from the tailings ponds at the Nordic site (Dave et al, 1982).

No other data pertaining to the mineralogy of the drift units were found. Based on the geological setting, it is most likely clays in the area are rock flour essentially of Precambrian igneous rock origin. Therefore, it is likely the mineralogy is predominantly quartz, illite, feldspar, amphiboles, chlorite and mica.

The petrography of the tills reflect the composition of the bedrock in the vicinity.

8.9 Geochemistry

Groundwater and surface water quality data are given in Table 8-3. Based on these data the pH of the ground and surface water is generally around 7. The radiochemical and heavy metal content of the discharge are within those concentrations specified in the mine's operating license.

Water discharged from each tailings impoundment is treated with lime and/or barium chloride before discharge into the Serpent River Basin. Water quality data are monitored by both the mining companies and the Ontario Ministry of the Environment to ensure discharged waters comply with either Provincial surface water guidelines and/or Federal mining discharge effluent quality standards.

8.10 Barrier Materials

Current Barriers

Earth material seepage barriers currently utilized in the Elliot lake waste management structures include:

- natural geologic barriers of peat, silt, sand, gravel, till and bedrock.
- engineered barriers consisting of compacted till with sand and gravel filters and drains.

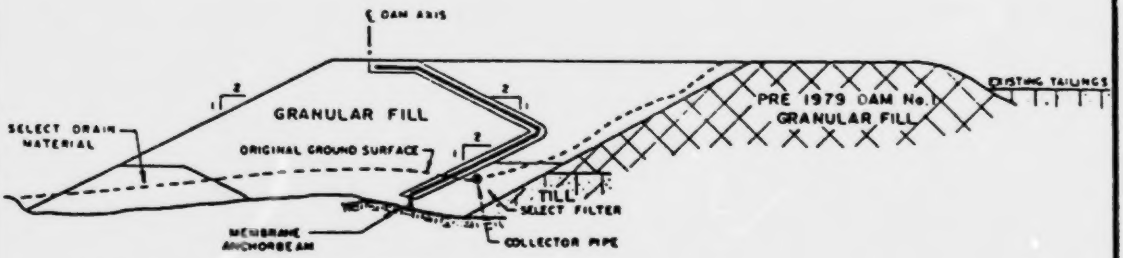
Typical dam sections indicating how these materials are utilized are illustrated in Figures 8-6 and 8-7. The properties reported in Table 8-4

TABLE 8-3
WATER ANALYSIS RESULTS, ELLIOT LAKE AREA

LOCATION PARAMETER	HWY 17 *		DEPOT LK. OUTLET *		PECORS LK. OUTLET *		CROTCH LK. **	
	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.
CONDUCTIVITY mhos/cm	270	154	242	102	325	220		
pH	7.3	6.58	7.3	6.6	7.25	7.01	7.5	6.5
TOTAL SUSPENDED SOLIDS	2.85	1.02	18.8	1	-	-		
ALKALINITY	9.1	6.1	40.6	10.8	14.2	10.6		
CHLORIDES (Cl)	10.1	6.3	18.2	3.7	-	-		
SULPHATES (SO4)	81.9	42.8	67.2	31.8	100	6.22		
PHOSPHOROUS TOTAL	0.015	0.002	0.074	0.004	0.024	0.001		
TOTAL KJELDAHL	1.1	0.61	0.670	0.29	0.54	0.29		
FREE AMMONIA	0.79	0.346	0.22	0.012	0.306	0.038	2	0.4
TOTAL NITRATES	3.3	1.6	0.885	0.205	1.16	0.045	0.6	0.2
COPPER (Cu)	0.003	0.001	0.003	0.003	0.002	0.001	0.02	0.005
LEAD (Pb)	0.003	0.003	<0.003	-	1.9	0.003	-	-
ZINC (Zn)	0.053	0.003	0.012	0.012	0.21	0.002	1	0.02
NICKEL (Ni)	0.003	0.002	0.001	0.001	0.003	-	-	-
IRON (Fe)	0.205	0.04	1.1	1.1	0.185	0.053	0.2	0.01
RADIUM 226 (mBq/L)	50	40	90	20	100	80	444	74
GROSS ALPHA (mBq/L)	380	160	370	50	460	250		
GROSS BETA (mBq/L)	240	160	190	60	250	110		
URANIUM 238 (microgram/L)	4	3	3	-	<3	-	-	-

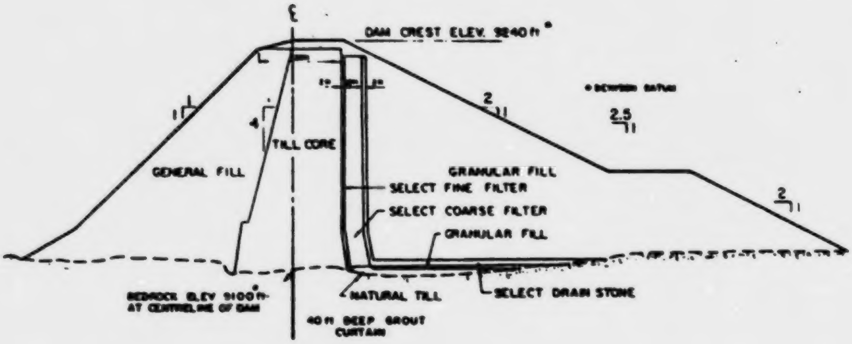
* Denotes Surface Water (Myslik, 1985)
** Ground Water (Boyd et al, 1982)

NOTE: Concentrations in mg/L unless otherwise noted



WILLIAMS LAKE, Dam 1

(After Reades et. al, 1981)



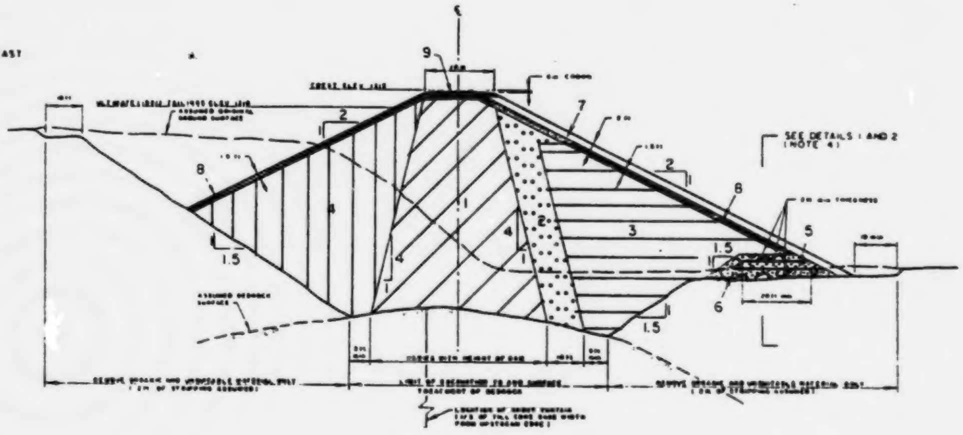
DENISON MINE, Dam 17

(After Reades et. al, 1982)

NOT TO SCALE

TYPICAL DAM PROFILES

FIGURE 8-6

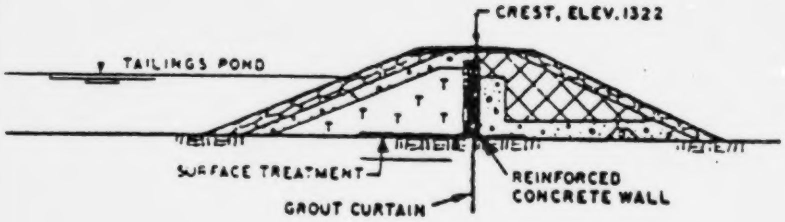


QUIRKE, Dam K_1

LEGEND

① CORE – GLACIAL TILL
② FILTER – PROCESSED SAND
③ DOWNSTREAM SHELL – SAND AND GRAVEL
④ UPSTREAM SHELL – TAILINGS SAND
⑤ DRAIN – PROCESSED GRAVEL
⑥ FILTER – PROCESSED COARSE SAND
⑦ EROSION PROTECTION – COBBLES
⑧ BEDDING/EROSION PROTECTION – SELECT SAND AND GRAVEL
⑨ ROAD SURFACING – GRAVEL

(After Golder, 1981 I)



▨ GRANULAR SURFACING
▨ WASTE ROCK RIP-RAP
▨ SELECT GRANULAR
▨ NON-SELECT GRANULAR
▨ SILTY SAND TILL
☐ BEDDING SAND
— MEMBRANE
☐ CONCRETE
▨ BEDROCK

PANEL MINE, Dam F

(After Pullen & Davis, 1981)

NOT TO SCALE

TYPICAL DAM PROFILES

FIGURE 8-7

TABLE 8-4
PHYSICAL PROPERTIES OF LOCAL CONSTRUCTION MATERIALS

PHYSICAL PROPERTIES		SILT TILL	SAND & GRAVEL
GRADATION (% by weight)	Gravel	10-40	5-50
	Sand	35-50	45-95
	Silt	20-30	0-20
	Clay	5-10	-
SPECIFIC GRAVITY		2.67	2.64
IN SITU WATER CONTENT (%)		8-9	-
ATTERBERG LIMITS	Liquid Limit (%)	14	N/A
	Plasticity Index (%)	2	N/A
COMPACTION CHARACTERISTICS (Standard Proctor)	Water content (%)	8	11
	Dry Unit Weight (kN/m3)	20.6	18.1
EFFECTIVE SHEAR STRENGTH			
Angle of internal friction (degrees)		37	35
Cohesion (kPa)		0	0
DYNAMIC STRENGTH Kc=1 (cyclic stress for failure at 6 cycles)		0.35	0.36
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		10-6 to 4X10-10	-
CONSOLIDATION CHARACTERISTICS			
Compression index		0.04-0.05	-
Coefficient of Consolidation (cm2/s)		0.2-0.1	-

(After Reades et al, 1982, & Golder, 1980a & 1981e) indicate that material selection and compaction can provide material with a coefficient of hydraulic conductivity as low as 4×10^{-10} m/s.

Potential Barriers

The silty till is abundant in the Elliot Lake area and is the principal candidate material for future construction of low hydraulic conductivity barriers. Results have shown that it can be placed to form a suitable barrier. Some lacustrine silt and peat also exist in the area, but data on their properties are scarce.

9.0 DERIVATION OF SEEPAGE QUALITY FROM URANIUM TAILINGS

9.1 Ore Chemistry and Mineralogy

The ore types from three uranium producing areas in Canada will be examined in this study. These areas are:

- Elliot Lake type, pyrite-bearing (sulphide) ore;
- Key Lake type, nickel/arsenic sulphide ore; and,
- Rabbit Lake type, "clean", low sulphide ore

The major mineral species in each ore are a factor in controlling the tailings and tailings pore water chemistry. The other major factor is the process and process chemicals used. Knowing these factors, a range of pore water compositions can be derived for each ore.

The principal uranium-bearing and gangue mineral species in the 3 ore types are summarized in Table 9-1, and an abbreviated chemical composition of the ore, in terms of both major species and "potentially environmentally sensitive" species, is presented in Table 9-2. General chemical characteristics have been assigned to the mineral species, to give an indication of their possible contribution to the tailings and tailings pore water quality.

9.2 Ore Process - Treatment Systems

Each of the 3 types of Canadian uranium ore may require a different process technology to remove the uranium. These are discussed separately below:

TABLE 9-1
COMPARISON OF MINERALOGY ORE TYPES - PRINCIPAL SPECIES

	ELLIOT LAKE ORE	KEY LAKE ORE	RABBIT LAKE ORE
ORE MINERALS	Brannerite (U, Ti02) Uraninite (U) Monazite (Ce, La, PO4) Uranothorite (U, Al, Si02)	Pitchblende* (U) Coffinite (U)	Pitchblende (U) Coffinite (U) Sklodowskite (Mg, U, Si02)
GANGUE MINERALS	Quartz Si02 (Chert) Si02 Sericite (Al, Si03) Feldspars (Na/K, Al, Si02) Pyrite FeS2 Ti minerals (Ti02)	Quartz Si02 Chlorite (Mg, Fe, Al) Gersdorffite NiAsS Millerite NiS	Quartz Si02 Calcite CaCO3 Phyllosilicates (Al, Si03)

* Both Key Lake and Collins Bay B-Zone

TABLE 9-2
COMPARISON OF THE CHEMICAL ANALYSIS OF ORE TYPES

		ELLIOT LAKE ORE	KEY LAKE ORE		RABBIT LAKE ORE	
			Key Lake	Collins Bay-B	Cluff Lake	Rabbit Lake
Major species important in tailings which could impact barrier (%)	Si02	80	50		70	
	Fe	3-5	3-3.5	1-3	1.5	N/A
	S	2-4	0.8-1.0	0.1	0.03	N/A
	Al	3-4	9-10		5.66	
	Ti	0.08	0.4-0.6		0.02	
	**CO2	0.2	1	0.2	0.04	2-3
Potentially environmentally sensitive species (ppm)	Cu	70	300-900		80	
	Zn	50	300-800		70	
	Pb	400			150	
	Ba	200			20	
	F	200				
	PO4	1000-2000	1500	200	500	
	Ni	30	10,000-25,000*	400		2000
	As	<50	1,0000-15,000*	5000	10	100
	V	<10	80		200	30
	Co	50	800			200
	Mo	<10	60-300		200	
	Th230 (Bq/g)				0.2	
	Ra226 (Bq/g)	11	220	60	18	30

* Can be considered major species

** Carbonate content in ores is usually reported as % CO2 equivalent

ELLIOT LAKE TYPE ORE

At the four mines in the Elliot Lake area:

- Denison Mine;
- Quirke Mine;
- Panel Mine; and,
- Stanleigh Mine,

four process-treatment possibilities exist. The four processes are summarized schematically in Figure 9-1. From Figure 9-1, the alternative chemicals and process steps for a generalized extraction process for this ore type are given. The process options are:

- H_2SO_4 extraction + HNO_3 stripping of resin + NH_4OH ppt; or,

- H_2SO_4 extraction + H_2SO_4 stripping of resin + $Mg(OH)_2$ ppt

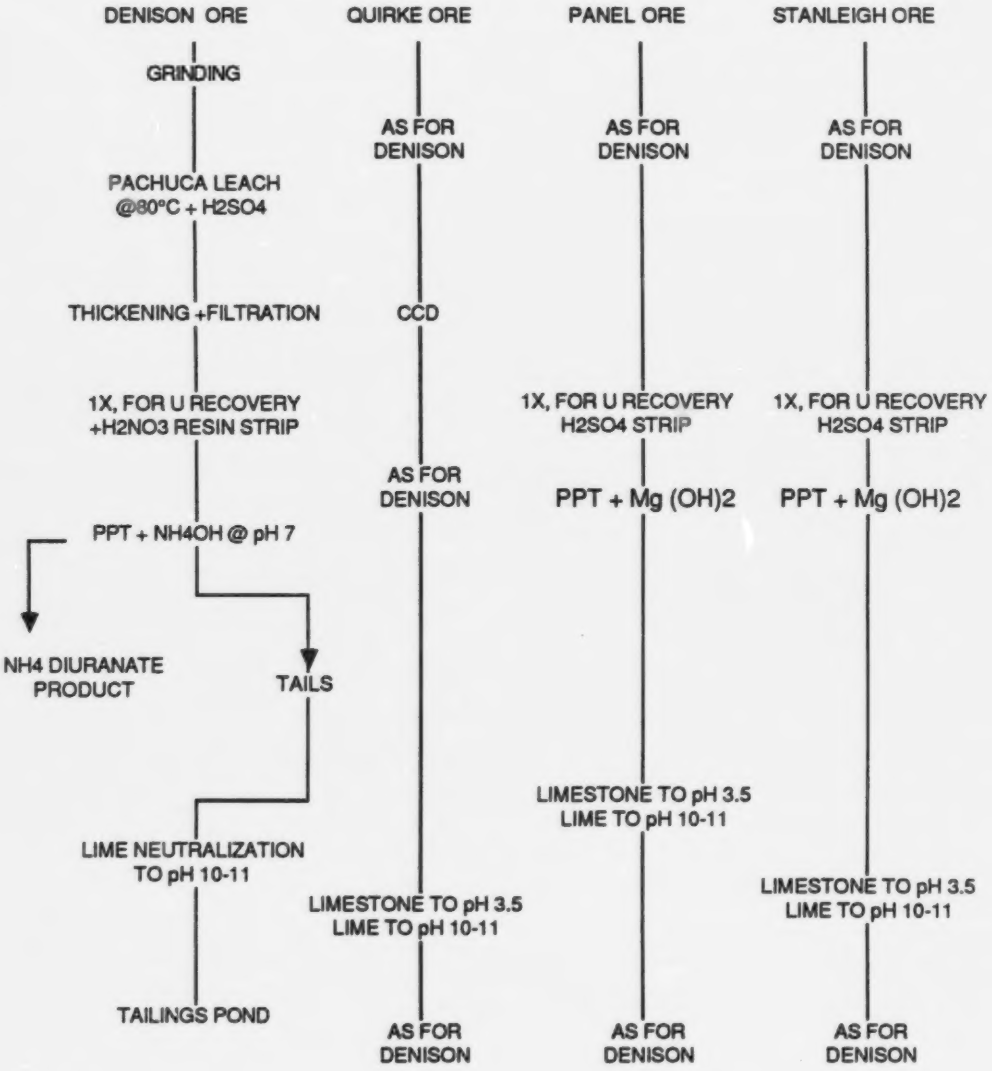
Imposed on these processes are two alternative neturalization processes for the tailings prior to discharge to the tailings disposal facility:

- lime ($Ca(OH)_2$) neutralization to pH 10-11*; or,

- limestone ($CaCO_3$) neutralization to pH 3.5 and then
  lime ($Ca(OH)_2$) neutralization to pH 10-11*

  (*$BaCl_2$ is added to decant water prior to discharge, but not to tailings slurry)

Alternatives to the process/neutralization chemicals added to the ore and to the tailings become:


DENISON ORE
QUIRKE ORE
PANEL ORE
STANLEIGH ORE
GRINDING
AS FOR DENISON
AS FOR DENISON
AS FOR DENISON
PACHUCA LEACH @80°C + H2SO4
THICKENING +FILTRATION
CCD
1X, FOR U RECOVERY +H2NO3 RESIN STRIP
1X, FOR U RECOVERY H2SO4 STRIP
1X, FOR U RECOVERY H2SO4 STRIP
AS FOR DENISON
PPT + Mg (OH)2
PPT + Mg (OH)2
PPT + NH4OH @ pH 7
NH4 DIURANATE PRODUCT
TAILS
LIMESTONE TO pH 3.5 LIME TO pH 10-11
LIME NEUTRALIZATION TO pH 10-11
LIMESTONE TO pH 3.5 LIME TO pH 10-11
LIMESTONE TO pH 3.5 LIME TO pH 10-11
TAILINGS POND
AS FOR DENISON
AS FOR DENISON
AS FOR DENISON

CURRENT PROCESS ALTERNATIVES : ELLIOT LAKE TYPE ORE

FIGURE 9-1

- $H_2SO_4/HNO_3/NH_4OH$ plus $Ca(OH)_2$; or, $CaCO_3 + Ca(OH)_2$
- $H_2SO_4/Mg(OH)_2$ plus $Ca(OH)_2$; or $CaCO_3 + Ca(OH)_2$

KEY LAKE TYPE ORE

Current producers milling this type of Ni/As bearing ore are:

- Key Lake; and
- Collins Bay B-Zone (modified Rabbit Lake Mill).

The two processes in operation are summarized in Figure 9-2. The Collins Bay B-Zone process is the modification to the Rabbit Lake Mill to allow for the presence of Ni and As in the ore. The two process options are:

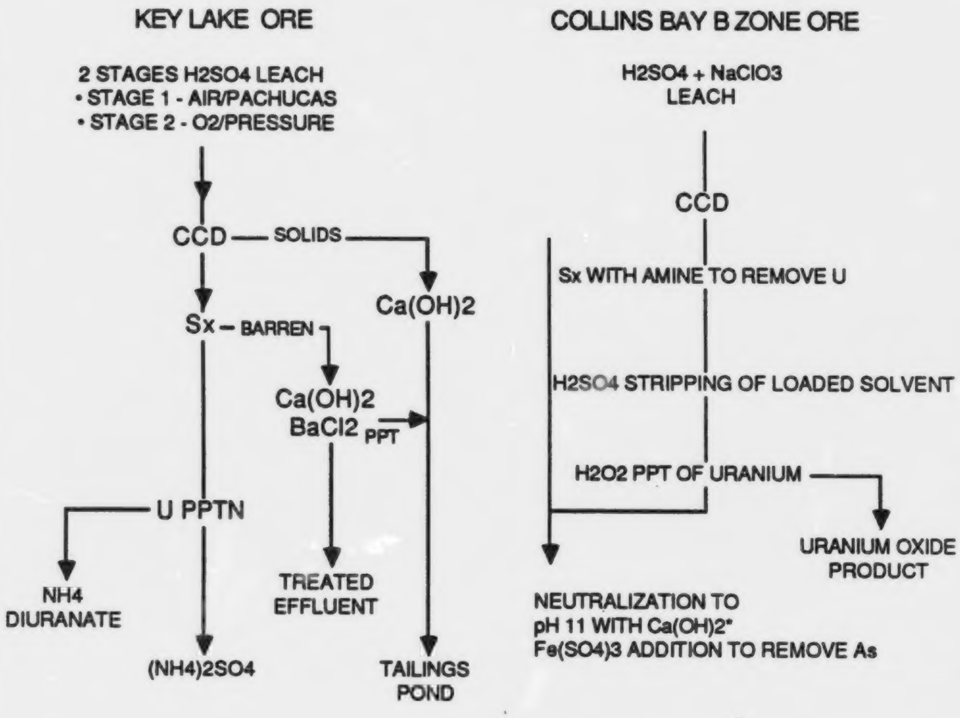
- $H_2SO_4/air/O_2$ extraction + SX + NH_4OH stripping/ppt; or,

- $H_2SO_4/NaClO_3$ + SX + H_2SO_4 stripping + H_2O_2 ppt.

Imposed on these processes are the possible neutralization alternatives:

- lime ($Ca(OH)_2$) neutralization to pH 10; or,
- lime ($Ca(OH)_2$) neutralization to pH 10 and $Fe_2(SO_4)_3$ addition to precipitate.

Alternatives for the process/neutralization chemicals added to the ore and to the tailings become:



*NOTE: SEPARATE NEUTRALIZATION OF LEACH RESIDUE AND RAFFINATE. Fe2(SO4)3 ALSO ADDED TO RAFFINATE TREATMENT.
H3PO4 ADDED TO PREGNANT STRIP LIQUOR AHEAD OF U PRECIPITATION TO REMOVE ZIRCONIUM.
(PPT IS PUMPED TO TAILS)

CURRENT PROCESS ALTERNATIVES : KEY LAKE TYPE ORE

FIGURE 9-2

- H_2SO_4/amine/NH_4OH, plus $Ca(OH)_2$ or $Ca(OH)_2$ + $Fe_2(SO_4)_3$;
- H_2SO_4/amine/H_2O_2/H_3PO_4*, plus $Ca(OH)_2$ or $Ca(OH)_2$ + $Fe_2(SO_4)_3$.

(* H_3PO_4 added to Collins Bay B-Zone ore)

RABBIT LAKE TYPE ORE

Until recently, the current producers milling the low sulphide, "clean" uranium ore were:

- Cluff Lake Mine (Phase II circuit); and,
- Rabbit Lake Mine.

The two processes are summarized in Figure 9-3. The process options are:

- H_2SO_4/$NaClO_3$ extraction + SX amine + $Mg(OH)_2$ ppt with Na_2CO_3 regeneration; or,

- H_2SO_4/$NaClO_3$ extraction + SX and NH_42 (SO_4) stripping + NH_4OH ppt

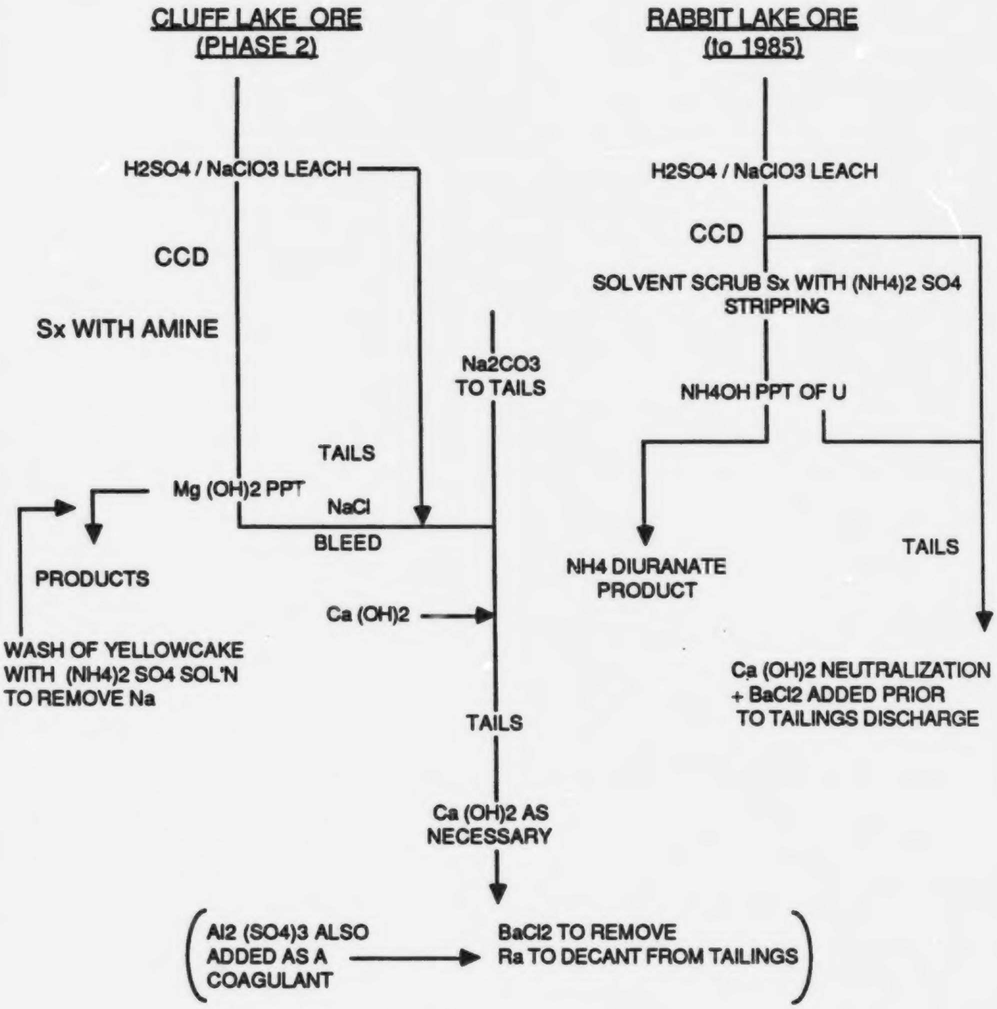
Imposed on these processes is the only one tailings neutralization scenario:

- $Ca(OH)_2$ to pH 10-11.

Alternatives of the process/neutralization chemicals added to the ore and to the tailings become:

- H_2SO_4/$NaClO_3$/amine/$Mg(OH)_2$ plus $Ca(OH)_2$ + $BaCl_2$; or,

- H_2SO_4/$NaClO_3$/"solvent"/$NH_2(SO_4)$ NH_4OH plus $Ca(OH)_2$ + $BaCl_2$.



NOTE: Na2 CO3 REGENERATION IS ALSO USED IN KEY LAKE, COLLINS BAY AND RABBIT LAKE

CURRENT PROCESS ALTERNATIVES : RABBIT LAKE TYPE ORE

Figure 9-3

SUMMARY

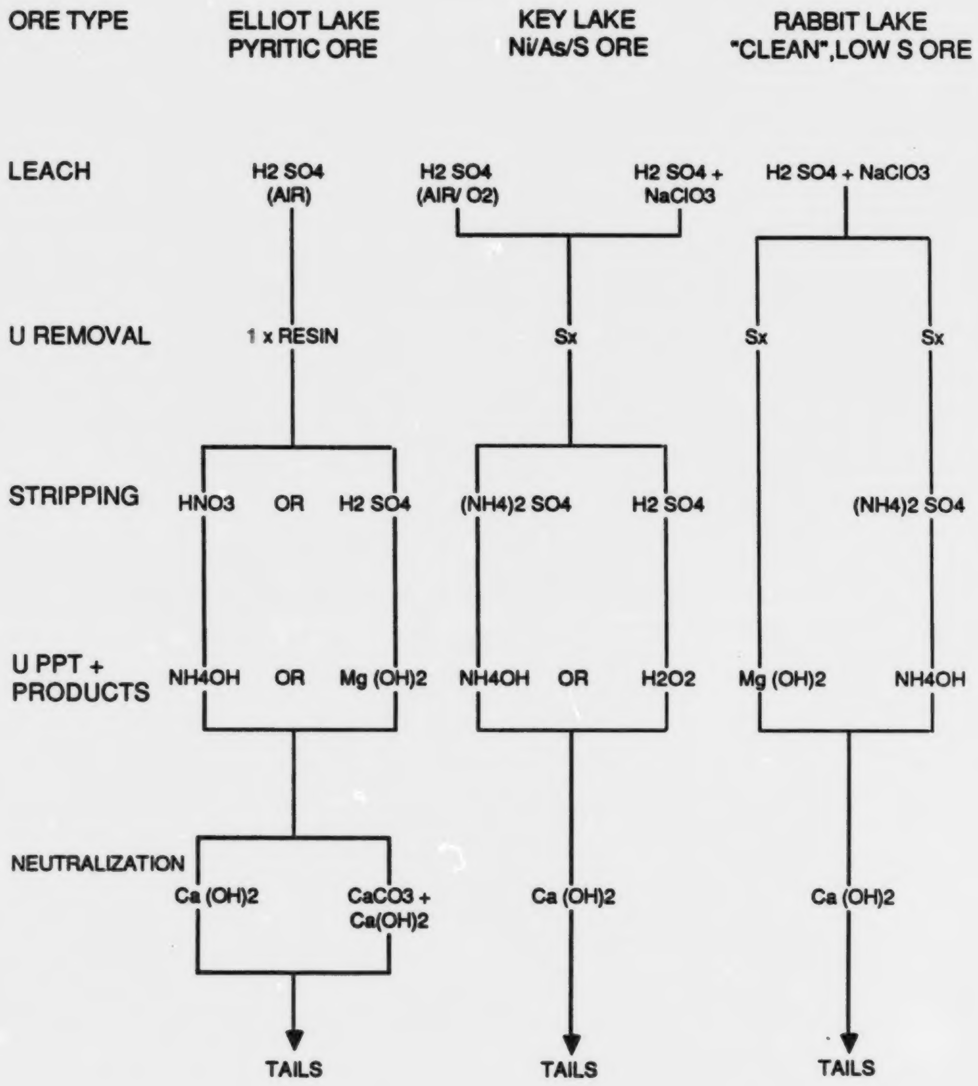
The processes and process variations for the 3 ore types are summarized in a single figure, Figure 9-4. If these processes are combined and the major elements considered in terms of the possible effects on the composition of the tailings, tailings pore water and tailings seepage water, the following list results:*

- acidification (H_2SO_4 addition);
- oxidation ($NaClO_3$ or air oxygen);
- selective removal (SX or IX);
- addition of small amounts of an organic phase (amine/isodeconal/kerosene);
- acid or alkaline stripping with H_2SO_4 or HNO_3 or NH_3 aqueous;
- precipitation with NH_4OH or $Mg(OH)_2$ or H_2O_2;
- neutralization with ($CaCO_3$), $Ca(OH)_2$ to its ultimate pH 10-11;
- radium removal ($BaCl_2$ ppt of $BaRaSO_4$), but normally only on tailings decant water; and,
- optional precipitation ($Fe_2(SO_4)_3$ removal of As).

(* H_3PO_4 addition to remove zirconium is practiced on Collins Bay B-Zone ore. This does not materially affect reactions with natural barriers).

9.3 Tailings Pore Water Characteristics Based on the Ore and the Ore the Processing System

The objective of this section is to define the initial quality of the process controlled tailings pore water based on:



COMPARISON OF PROCESS/TREATMENT ALTERNATES BY GENERIC ORE TYPES

Figure 9-4

- an assessment of the ore plus the processing and neutralization treatment; and,
- actual measured values for the 3 ore type areas.

By combining these estimates and measurements, a "short list" of the more important species in the tailings pore water for the 3 ore types can be derived. This pore water composition requires further modification to account for the effects of aging of the tailings as discussed in Section 9.4.

9.3.1 Estimate of the Process Controlled Pore Water Quality from Ore/Process Chemistry

Table 9-3 gives an estimation of the pore water chemistry that could be expected based on the nature of the ore and the particular mill process. Specific points to note are:

- sulphate and, hence, TDS values will be dependent on the amount of magnesium and/or sodium added to the process as they will affect the calcium sulphate (gypsum) solubility (the sulphate levels are also dependent on pH).

- ammonia, magnesium, sodium and chloride levels are dependent on their addition as process chemicals (aqueous NH_3, MgO slurry, $NaClO_3$ and Na_2CO_3);

- arsenic levels are controlled by either the solubility of calcium or ferric arsenate;

- iron levels are pH controlled in an initially oxidizing system; and,

- discharge pH values are controlled by lime addition in the neutralization circuit.

TABLE 9-3
ESTIMATED DISCHARGE WATER COMPOSITIONS FROM ORE/PROCESS CHEMISTRY FOR THREE ORE TYPES - PRINCIPAL COMPONENTS ONLY

PARAMETER (oxidation)	ELLIOT LAKE TYPE	KEY LAKE TYPE		RABBIT LAKE TYPE	
	(air)	Key Lake (oxygen)	Collins Bay-B (chlorate)	Cluff Lake (chlorate)	Rabbit Lake (chlorate)
PH (units)	10	10	8-10	9	7
TDS	2000-3000	2000-3000	2000-4000	5000-8000	5000-8000
Ca	600	600	600-800	800-1000	600-1000
SO4	1500-2500	1500	1500-2500	3000-5000	3000-5000
Si	<5	<5	<5	<5	<5
Al	0.5	0.2-6	0.5	0.1	0.1
NH3	100(a)	100(a)	<10	<10	500(a)
NO3	+10	+10	+10	+10	+10
Na	<50	<50	500(g)	1000(g)	150(g)
Cl	<50	<50	500(g)	1000(g)	200(g)
Ni	<0.5	<0.5	<0.5(e)	<0.5	<0.5
As	<0.1	5(1-10)	5(1-10)(f)	<0.1	<0.1
Fe	0.1-1.0	0.1-1.0	0.1-1.0	1	1
Mg	500(b)	<1	<1	500(b)	<1
Ra226 (Bq/L)	10-30(c)	10-50	<10	10-50	1-20

NOTE: All values are ppm, except where noted

(a) NH4OH ppt process
(b) Mg(OH)2 ppt process
(c) <5 Bq/L for oxidized tailings (i.e. Nordic Plume) but higher for unoxidized (fresh) tailings water
(d) Inferred from decant H2O pH7
(e) Depends on whether pH is 8 or 10; range may be 0.5-5 mg/L
(f) Fe2(SO4)3 treatment should control As to less than 1 ppm
(g) NaC103 addition gives high Na and Cl residual values, while Cluff Lake has additional NaCl used for stripping, with a bleed to tailings

9.3.2 Tailings Pore Water Compositions

Measured tailings pore water compositions are given in Table 9-4. Information for many species is sparse, particularly for the Elliot Lake neutralized tailings. Also, there is a wide variation in the Key Lake data. The variations for Key Lake were probably caused by variation in mill operation during the initial startup period when these data were collected. Certainly, pH 6.4 is well below the operating objective of pH 11.

Comparison of Tables 9-3 and 9-4 however, indicates that the general character of the initial tailings pore water that would be predicted by consideration of the ore and the process is not too different from that measured in the field. The major dissolved components in the tailings pore water are more dependent on the process and neutralization chemicals added than on the initial ore composition. Initial ore composition is a more important factor in the trace element concentrations and in the quality of pore water at later stages in the geochemical evolution.

As noted in Section 9.3.1, discharge pH values are controlled by lime addition in the neutralization circuit. In some other tailings, it is apparent that no neutralization was practiced and the tailings were discharged at the extraction pH value. This could give rise to two additional tailings pore water compositions:

- a pH 1-2, sulphate bearing composition which remains stable over a significant period of time, if the tailings themselves were also acid generating, i.e., pyrite bearing; or,

- an initial pH 1-2, sulphate bearing composition which might change with time by reaction either with resistant neutralizing minerals in the tailings (e.g., calcite/dolomite) which were not dissolved in the initial extraction process, or by leaching with pH 5-6 precipitation.

TABLE 9-4
TAILINGS PORE WATER COMPOSITIONS
Measured for Three Ore Types

PARAMETER	ELLIOT LAKE TAILINGS*	KEY LAKE TYPE (est)		RABBIT LAKE TAILINGS
		Key Lake Tailings**	Collins Bay B (est)	
pH	8-10	6.4-10.9	10	5.0-8.5
TDS	2500-3500	2500-2600	4000-6000	6000-8000
Fe	0.5-1.5	0.02-0.05	0.1	0.25
SO4	1000-2500	1500-1700	2970	6400
Ca	400-500	600-750	725	468
Mg	50-500	0.1-5	<0.1	960
Mn	N/A	<0.1	<0.5	0.4
Na	N/A	40-120	500	155
K	N/A	5-30	72	30
Al	N/A	<0.1-3	N/A	N/A
Cu	<.1	<0.05-0.1	<0.05	0.06
Co	N/A	<0.02	0.1	0.15
Zn	<.1	<.05	<0.2	0.06
Pb	<.1	<0.02-0.08	0.3	0.1
Ni	<.1	0.04-0.5	1.5	0.4
Si02	N/A	2-4	N/A	N/A
Cl	N/A	4-50	500	210
NH3-N	10-100	10-30	3.8	350
NO3-N	10-30	<0.1	1	5
As	N/A	0.3-2.2	1.5	0.001
Cr	N/A	<0.02	<0.05	0.02
Mo	N/A	0.5-3	N/A	N/A
U	0.01-0.03	0.001-0.01	<0.05	0.03-0.5
W	N/A	0.2-2	N/A	N/A
Th230 (Bq/L)	N/A	0.3-1.6	N/A	1.6-5.5
Ra226 (Bq/L)	10-55	10-15	N/A	1-18

NOTE: Concentrations in mg/L unless otherwise noted

* Neutralized tailings i.e. refers to "fresh", unweathered tailings

** Knight and Piesold, 1985, 1986.

Note : Variations within one type are greater than variations between types; therefore a single pore water composition can be used.

> The net effect would be to increase the pH to between pH 4 and neutral and hence change the pore water composition.

With the above qualifications with respect to incomplete neutralization during operations, the process controlled tailings water compositions are derived below.

9.3.3 Process Controlled Tailings Pore Water Characteristics

By combining the estimate of tailings pore water composition in Table 9-3 with the range of measured values in Table 9-4, a set of chemical characteristics can be derived for each of the three ore types. These data, for "fresh", unaged pore water are given in Table 9-5.

It is because of the process variations that there are two individual pore water compositions given in Table 9-5 for each ore type. These have been rationalized, by using ranges where there are some differences in the process type.

Table 9-6 combines the two data sets for each ore type into one composite analysis for each. It is apparent that the overall chemical composition of the pore water is similar; a calcium sulphate, moderate to high pH chemical system. Given the nature of this project, to evaluate the general effects on barrier materials of tailings seepage, consideration of a single composition of this general style would not be very different than consideration of the individual tailings composition. Consequently, it is not unreasonable to use a single "generic" tailings pore water composition, although, it is recognized that there is indeed a range of values for individual parameters both at individual sites and between sites. For the purposes of this study, this range is not significant.

TABLE 9-5
"GENERIC" FRESH TAILINGS PORE WATER COMPOSITIONS OF MAJOR/SIGNIFICANT* SPECIES FOR DIFFERENT PROCESS OPTIONS

PARAMETER	ELLIOT LAKE TYPE		KEY LAKE TYPE		RABBIT LAKE TYPE	
	NH40H process	Mg(OH)2 process	Key Lake	Collins Bay B	Cluff Lake	Rabbit Lake
pH (units)	10	10	10	10	9	7
TDS	2500	3500	2500	4500	8000	8000
Ca	500	500	600	800	600	600
S04	1500	2000	1500	2500	5000	5000
NH3	100	<10	30	<10	<10	350
Na	<50	<50	<50	500	600	150
Cl	<50	<50	<50	600	700	200
Fe	<1	<1	<1	<1	<1	<1
Mg	<1	500	5	<1	500	900
As	<0.1	<0.1	2	2	<0.1	<0.1
Ra226 (Bq/L)	20	20	50	<20	<20	<20

NOTE: All values are ppm, except where noted

* Major/Significant refers to species which may impact on natural barrier behaviour

TABLE 9-6
"GENERIC" FRESH TAILINGS PORE WATER COMPOSITIONS OF MAJOR/SIGNIFICANT* SPECIES FOR COMBINED PROCESS OPTIONS

PARAMETER	ELLIOT LAKE TYPE	KEY LAKE TYPE	RABBIT LAKE TYPE
pH	10	10	7-9
TDS	2500-3500	2500-4500	8000
Ca	500	600-800	600
S04	1500-2500	1500-2500	5000
NH3	<10-100	<10-30	<10-350
Na	<50	<50-500	150-600
Cl	<50	<50-600	200-700
Fe	<1	<1	<1
Ni	<.1	1	<.1
Mg	50-500	<1-5	500-900
As	<0.1	2	<0.1
Ra226 (Bq/L)	20	50	<20

NOTE: All values are ppm, except where noted

* Major/Significant refers to species which may impact on natural barrier behaviour

Table 9-7 therefore further consolidates the actual pore water quality data to yield a "generic" description of the process controlled pore water composition. This description can be used for the purpose of understanding the geochemical evolution of the pore water compositions (Section 9.6) and the effects of seepage on the natural barrier materials.

9.4 Geochemical Evolution of Pore Water Quality: Change of Tailings Pore Water Composition with Time

The potential for environmental impact due to release of uranium tailings seepage has prompted studies of contaminant migration of seepage in groundwater. In particular, detailed studies in the Elliot Lake area have shown that there is potential for contaminant migration from neutralized, pyrite-bearing uranium tailings. A feature of many studies, both at Elliot Lake and elsewhere, is that the tailings seepage chemistry has been shown to differ with time from the initial tailings pore water composition on discharge. Consequently, there is a time component in consideration of tailings seepage composition. The initial estimates of process controlled pore water compositions, given in Table 9-7, require modification to account for such changes over time. This section of the report addresses the geochemical evolution of pore water quality that occur over time. The stages of this evolution are defined here, based on the major elements that control the quality of the pore water during a particular stage. The stages of evolution of the geochemistry of the pore water are:

- process controlled (already discussed above);
- sulphide oxidation if the sulphides are oxidizable;
- secondary solution stage herein called re-solution; and,
- long-term leaching.

A "generic" composition of the pore water characteristic of these four evolutionary stages are presented in Table 9-8 and a description of each stage

TABLE 9-7
"GENERIC" PROCESS CONTROLLED TAILINGS PORE WATER COMPOSITION (ALL ORES)*

PARAMETER	RANGE***	ESTIMATE***
pH	7-10	10
TDS	2500-8000	4500 (8000)
Ca	500-800	600
S04	1500-6500 **	3000 (5000) **
NH3	<10-500	300
Na	<50-600	100
Cl	<50-700	200
Fe	<1	<1
Mg	<1-900 **	100 (800) **
As	<0.1-2	1
Ra226 (Bq/L)	<10-50	<20
Ai	<5-20	<10
Si	<5-20	<10

* All values are mg/l, unless stated otherwise

** High magnesium values increase sulphate solubility: applies specifically to Rabbit Lake area and values for this case are given in parenthesis.

***Notes:

1) While there is a distinct range in composition for pore water, a "generic" single composition has been developed for the purposes of examining the overall geochemical evolution of the tailings pore water and its effect on the behavior of natural barrier materials.

2) As only with Key Lake type. Ra is variable and heavy metals significant to Key Lake type ores, but have little effect on behavior of natural barrier materials.

TABLE 9-8
"GENERIC" PORE WATER QUALITY STAGES

PARAMETER	PROCESS CONTROLLED STAGE	SULPHIDE OXIDATION STAGE*	RE-SOLUTION STAGE ** Alternative 1 (sulphide oxidizes)	Alternative 2 (non-oxidation of sulphide)	LONG-TERM INFILTRATION PHASE
pH(units)	10	2	3.5	7.5	5
TDS	4500	30000	2500	2500	100
Ca	600	500	400	400	20
S04	3000	20000	1800	1200	10
NH3	300	<10	<10	<10	<1
Na	100	100	20	20	10
Cl	200	200	20	20	10
Fe	<1	10000 *	20	5	<1
Mg	100	200	50	<5	10
As	1	1	<1	<1	<0.1
Ra226 (Bq/L)	<20	<5	<20	<10	10
Al	<5	20	20	<5	5
Ni	<.01	1	<.1	<0.1-1	<.1
Si	<5	20	20	<5	5

* If pyrite or iron-bearing sulphide oxidizes

** May be accompanied by alteration of jarosite, in iron-bearing tailings follows. In the case of sulphides which do not oxidize, then the second stage is omitted and a modified third stage if operative.

INITIAL PROCESS CONTROLLED STAGE (ALL TAILINGS)

As discussed above, the initial quality of pore water found in the tailings, as deposition of the tailings proceeds, is controlled almost entirely by the milling process used to extract the uranium from the ore and the process used to neturalize the tailings prior to deposition.

The water chemistry of this stage is dominated by a basic pH and gypsum solubility. The actual TDS, and major cation and anion concentrations will be a function of process chemicals used. As can be seen on Table 9-7, the SO_4 concentration at 3,000 ppm is above the level that would result from gypsum solubility, and is explained by the presence of the Na, Mg and NH_3 ions introduced in the extraction process. Trace metal and radionuclides, except potentially U and Mo which have been reported as soluble species at basic pHs by several investigators (Shepherd and Brown, 1982; Cherry et al, 1981; White et al, 1984; among others), are of little concern at basic pH.

This is probably the shortest of the four evolutionary stages postulated. As soon as discharge takes place, the basic pH starts to move toward the neutral ranges. Data from Elliot Lake (Cherry et al, 1982) demonstrates this fairly rapid decline in pH. The reason for the lowering of pH is due to a number of factors, including dissolution of mineral species; oxidation of sulphide minerals which produces hydrogen ions; and, introduction of slightly acidic precipitation, which, in turn, reacts with hydroxide ions present. If sulphides are not present in the tailings, as is expected for the "clean" Rabbit Lake ores, this stage will persist for a longer period. However, even for these "clean" ores, it is still expected that this stage will be relatively short lived. The probable maximum period will be about the same as the operational life of the impoundment.

SULPHIDE MINERAL OXIDATION (ELLIOT LAKE TYPE TAILINGS)

This stage of the evolution of tailings pore water is defined by the period during which oxidation of sulphide minerals present in the tailings produces hydrogen ions, reduces pH and re-dissolves the minerals previously precipitated as a result of process neutralization. The "generic" analysis for this stage, presented in Table 9-8, shows the effect of the lowered pH in terms of significant increases in TDS, sulphate and iron concentrations. All other trace metals, originally present in the tailings solution prior to neutralization, could be again present at essentially their original levels. Iron concentrations are high in the analysis in Table 9-8 because it is assumed that the sulphide mineral present is pyrite. If this is not the case, as may be true for the Key Lake ores, iron would not attain the concentration shown. For the "clean", i.e. non-sulphide ores, of Rabbit Lake, this stage of the geochemical evolution will theoretically not occur.

Documentation of this sulphide oxidation stage is provided by the experience reported for inactive Elliot Lake tailings. Reactions in the pyrite-bearing uranium tailings at Elliot Lake have been extensively studied Moffet and Tellier (1977); Cherry et al (1980); Snodgrass et al (1982); Dubrovsky et al (1985). Although many of these studies have been part of an assessment of solute transport from the tailings, they do address the compositional variations of pore water in the tailings as a precursor to this evaluation.

In essence, the studies show that pyrite is being oxidized in the upper part of the tailings mass causing changes in the pore water composition both above and below the zone of saturation in the tailings. The result of this process is a two layered compositional system: an upper layer of low pH, high TDS, sulphate and iron water exchanged by infiltration from rainfall or snowmelt; and, a lower neutral pH, moderate TDS zone reflecting the composition of the original mill process tailings discharge water.

Ferrous iron is shown also to be oxidized to ferric, with a resultant increase in acidity. However, residual calcium carbonate added during the neutralization of the tailings prior to discharge is reducing this acidity and liberating calcium to react with the available sulphate to precipitate gypsum (calcium sulphate). Coupled with such neutralization, reactions between the acidic pore water and aluminosilicates in the tailings cause further neutralization with an increase in aluminum concentration, despite some subsequent precipitation of aluminum as hydroxides or sulphates.

The data derived for the behavior of the Elliot Lake tailings reflect periods for tailings deposition and subsequent inactivity of the order of 20 to 30 years. This establishes an approximate beginning for this stage of pore water evolution. Determining the approximate duration of this stage is problematic.

Dubrovsky et al (1985) note a rate of migration downwards of the acidic zone in pyrite tailings of 0.2-2m/yr. This rate of downward advance is slower than the infiltration rate/seepage rate, due to the retardation of the acidic zone, through neutralization, during transport downwards. There is a capacity for acid generation until all the pyrite is oxidized, after which the tailings would be "flushed" with relatively low TDS, rainfall or snowmelt, infiltration. Given the present rate of infiltration, acid generation resulting in a high TDS, high sulphate and iron seepage water composition will continue for many decades.

Snodgrass et al (1982) attempted to erect a time scale for reactions in Elliot Lake tailings for those reactions which would effect the chemical composition of seepage. In summary, they suggest:

0 - 160 years
- sulphate production from pyrite oxidation in acid solution;
- calcium availability from acid neutralization by carbonates;

° calcium sulphate from gypsum solution;
° formation of jarosite and then geothite, which can limit iron in solution;

160 - 185 years ° increased calcium sulphate solution under acidic conditions;
° geothite solution increases iron concentrations;
° final oxidation of all pyrite;

185 - 400 years ° increasing pH to about 5-6; and,
° continued gypsum solution.

Modifying Snodgrass' time scale to be compatible with the evolutionary geochemical pore water stages proposed here, the time would be as follows:

0 - 20 years (or impoundment operational life)	Process Controlled Stage
20 - 200 years	Sulphide Oxidation Stage
200 - 600 years	Gypsum Leaching Stage (with aluminum precipitation)
600 - 1000+ years	Long-Term Leaching Stage

The modified scale would not be applicable, however, to the case where non-neutralized, acidic tailings have been discharged. Effectively, the acidic stage equivalent to the sulphide stage starts at year zero. If the tailings are not neutralized and pyrite bearing, ongoing oxidation of the pyrite will keep the pH low, probably in the same order of time as in the modified Snodgrass scale. If there were no pyrite in the tailings and the tailings have residual buffering capacity, due to non-reacted mineral species, then the acid stage will become very short and the system will more rapidly progress to the long term leaching stage, perhaps within 20 to 50 years.

RE-SOLUTION STAGE (ALL TAILINGS)

This stage of pore water quality begins when sulphide material oxidation has been completed, if sulphide minerals are present, or when infiltration induced leaching of the tailings mass begins to control the chemistry of pore water and seepage. Because data on this stage, and also the next stage, are very limited, experience, judgment and some element of conjecture form the basis for the prediction of the "generic" pore water composition of these stages.

For the resolution stage, two possible precursor conditions (and therefore sub-stages) are possible: one in which sulphide minerals exist and are oxidized; and, a second in which no sulphide oxidation occurs, where the process controlled stage directly preceeds this resolution stage.

Re-Solution Stage with Prior Oxidation Stage: Alternative 1

If sulphide minerals are present in the ore, the sulphide oxidation stage will precede this re-solution stage. In this case, the starting pore water quality will be dominated by low pH, high sulphate concentrations, soluble aluminum and large amounts of gypsum precipitated in the tailings mass. When sulphide oxidation stops, the control of pore water composition will result from the interaction of infiltrating surface water (rainfall and snowmelt) with the solid and liquid phases present in tailings. The principal process that will dictate the overall pore water composition during this stage will be the re-solution of the previously precipitated gypsum.

This process could proceed over a very long time and its duration is dependent on the quantity of gypsum present and the rate of infiltration. As predicted by Snodgrass et al (1982), for a maximum infiltration scenario on the Elliot

Lake tailings, solution of the gypsum precipitated in these tailings would take approximately 400 years. In addition, the precipitation of the soluble aluminum as $Al(OH)_3$, which will occur during this stage, will produce hydrogen ions and help to maintain the pH of the pore water at a level below that of the infiltrating meteoric water. As shown on Table 9-8, the pH for this stage is 8.5. This reflects the potential importance of the Al precipitation reactions, as described by Cherry el at (1982) and Dubrovsky et al (1985) as a determinent in the development of pore water composition during this stage.

Table 9-8 provides a comparison of the pore water quality which has been measured for the Elliot Lake tailings which are in the sulphide oxidation stage (column 2) with a prediction of pore water composition during the re-solution stage (column 3). The sulphide oxidation stage values (column 2) are based on measurements made at Elliot Lake by the authors cited earlier, confirmed by observations from the United States (Levins, 1980) and South Africa (Smith et al, 1984); they are defensible.

The theoretical end point of this stage will be when all the gypsum has been redissolved. At that point, the quality of infiltration water will become the dominant control of pore water composition. It is expected, in fact, that pore water will eventually be essentially the same as the infiltrating meteoric water, i.e. Stage 4.

Re-Solution Stage with No Prior Oxidation Stage: Alternative 2

The re-solution stage will occur even if the sulphide oxidation stage is absent in the evolutionary sequence. The difference is that process controlled stage pore water quality will be the starting point. Instead of a slight and gradual pH increased from 3 to 3.5, pH will drop from 10 to the long-term infiltration stage pH of 7. In both cases, this stage represents a transition from rather extreme pH levels to the stable condition of long-term infiltration. Gypsum re-solution will be a principal control of the bulk chemical composition, along with the process of mixing the pore water with rainfall infiltration. The composition given in Table 9-8, therefore represents an intermediate composition between the process controlled stage and long-term infiltration stage pore water. Aluminum precipitation reactions, important in the first alternative to this stage, will not occur here in the same manner. There may be some aluminum precipitation, however, as a gibbsite controlled system has a solubility low of about pH 6-7. The pH is reduced as a result of the introduction of meteoric infiltration water, which has a pH of about 5-6. The duration of this alternative will probably be of the same order as predicted for Alternative 1, approximately 400 years (Snodgrass et al, 1982). Since the sulphide oxidation stage is not included, however, the total lapsed time to arrive at the end of this stage will be about 200 years shorter than Alternative 1. Of course, the actual time for each phase to run its course will depend upon the specific bulk geochemical and hydrologic conditions of a site.

INFILTRATION STAGE (ALL TAILINGS)

The last stage of the generic evolution of pore water composition postulated here is the stage where infiltrating meteoric surface water becomes, in essence, the tailings pore water. During this stage, which will continue unabated apart from a climatic change, all geochemical reactions and resolution processes vigorous enough to significantly affect the quality of pore water, have ceased to be important. It is likely that continued alteration of clay minerals and silicates will provide soluble aluminum and silicon to the pore water, but at rates which are not important in an overall water quality sense. The pH and composition of the pore water of this stage is intended to be representative of the quality of normal precipitation in the area under consideration.

This stage of pore water evolution can be considered the stable base condition which will provide a steady-state pore water quality and yield seepage which results in essentially no impact to the environment.

Much of the above discussion cites data from Elliot Lake area, where considerable work of tailings geochemistry has been undertaken. It is worth examining, in a little more detail, the data available for Key Lake and Rabbit Lake to verify their compliance with the proposed "generic" evolution of seepage composition to be used in this study.

KEY LAKE

The available data for the Key Lake ore type with which to assess the potential long-term changes in pore water quality are sparse when compared with data from Elliot Lake. However, projected pore water quality data are available from Key Lake Mining Corporation (1982b), and predicted chemical changes in pore water composition were assessed by Senes Corporation, for Knight and Piesold Ltd. (1985b).

Key Lake Mining Corporation data are based on a model developed by Sherritt Gordon in 1979 and used to predict seepage composition vertically through deposited tailings. The significant species found in the solution were calcium at between 85 and 640 mg/L; magnesium 2.7 to 9.5 mg/L; iron 0.2 to 2.6 mg/L; and, silicon 3.7 to 4.5 mg/L. The pH of the seepage varied between pH 3.3 and 3.6. No sulphate data are available, but assuming stoichiometry (at least) between calcium and sulphate, the minimum sulphate levels would be between 210 and 1600 mg/L. At a pH of about 3.5, sulphate and iron levels could be expected to be significantly higher.

Leaching studies, reported by Knight and Piesold Ltd. (1985b), were used to predict long-term changes in seepage quality at Key Lake and the data compared observed values of tailings discharge, pore water and seepage. A summary of these data are given in Table 9-9.

Observational data indicate a potential for decreasing pore water pH with time to about pH 7, increasing sulphate levels to about 1500 mg/L i.e. approaching saturation. Leach tests used to predict on-going, longer term reactions suggest pH values in the range 5.6 to 9.9, with sulphate levels up to 1950 mg/L. Model predictions give pH values in the range 3.3 to 3.6, with calculated sulphate values in the order of 1600 mg/L or greater. With such a variation in pH values, and the implications such variation has on the concentrations of several of the species in tailings seepage, it is difficult to predict the chemical quality of long-term seepage from Key Lake "generic" tailings. Table 9-10 gives an estimate of the possible range of values for parameters of interest and a "best estimate" of longer term leaching.

The Key Lake ore contains about 1% sulphur, as compared with 3% to 10% in the Elliot Lake type of ore. The sulphur is as nickel/arsenic sulphide as opposed to pyrite. However, oxidation of sulphide cannot be excluded as a mechanism for decreasing pH in the longer term. Knight and Piesold Ltd. (1985b) postulate increasing sulphate (Section 10.2) as a result of oxidizing metallic sulphides, in the evaluation of geochemical controls on the tailings chemistry. This in itself implies a lowering of pH. They suggest, however, that the system will be buffered to pH 7 due to control by calcite dissolution equilibrium. Assuming complete and sufficient availability of calcium carbonate due to over-neutralization in the tailings prior to discharge, this medium will keep pH values to above neutrality. However, the presumption made is that the available carbonate leaches at a slower rate than the sulphide oxidizes, and is therefore available to react with the acidity provided until the sulphides are completely oxidized. Of concern, therefore, in the observation of a pH 7 value for seepage from Key Lake tailings are the pH 5.6 and pH 3.5 values produced in leach testing and model prediction of the tailings behavior.

TABLE 9.9
KEY LAKE TAILINGS CHEMISTRY

PARAMETER	TAILINGS DISCHARGE (observed)	TAILINGS PORE WATER (observed)	TAILINGS SEEPAGE (observed)	LEACH TESTS (Sherritt Gordon)	LEACH TEST (SRC 1985)	MODEL PREDICTION (KLMC 1982)
pH	6.4-12.1 ***	9.3-11.1	7.1-7.4	5.6-9.9	6.7-9.2	3.3-3.6
S04	1210-3450	1590-1720	1150-1470	1500-1950	1420-1620	290-1600 *
Ca	520-1050	655-780	374-550	364-840	610-660	85-640
Si	<0.1	<0.1	<0.1-0.13	0.3-3.7	-	3.7-4.5
As	0.8-2.2	0.1-0.2	<0.02	<0.1	<0.03	0.1 **
Ni	0.01-95	0.02-0.09	0.04-0.09	<0.1-1.6	0.03-0.3	0.4
Zn	0.002-0.3	0.02-0.03	0.06-0.21	<0.01-4	<0.01-0.05	-
Ra226 (Bq/L)	25-420	9.5-55	10-45	35-41	30.55	3.1

* Calculated as minimum based on stoichiometry with calcium
** Initial level in supernatant is 5.7 mg/L
*** Low values during mill start-up

(from Knight & Piesold, 1985)

If the pH were to fall below neutrality, the levels of pH controlled species would tend to increase (i.e. sulphate, iron, aluminum and silicon). Therefore, it is difficult to know if the Key Lake type of tailings will follow the oxidation route to long-term leach quality or the second alternative of leaching only. The "best estimate" data in Table 9-10, however, are not inconsistent with the intermediate quality of the gypsum re-solution phase in the tailings evolution.

RABBIT LAKE

With the absence of data on pore water composition in the Cluff Lake tailings, derivation of seepage composition for the Rabbit Lake type of pore water is based on Rabbit Lake data only. Table 9-11 indicates pore water composition in the Rabbit Lake tailings with pH values in the range of pH 5 to 8.5, TDS values up to 8000 mg/L and sulphate levels of 6500 mg/L. As Rabbit Lake "generic" ore is considered "clean" (i.e. essentially free of sulphides), the eventual seepage chemistry will be dependent on leaching by infiltration of precipitation at a pH value down to about pH 5, having passed through the intermediate gypsum dissolution phase. Table 9-11 gives a "best estimate" seepage chemistry for the Rabbit Lake tailings for the intermediate phase. Higher sulphate values at this stage, compared to the generic case in Table 9-8, reflect the higher initial values from the process neturalization. These are probably a function of high magnesium values in the pore water.

SUMMARY

This evaluation has examined the processes which control the composition of pore water, and, hence, seepage from uranium mill tailings in Canada. The pore water composition is dominated by the effects of process reagents, particularly sulphuric acid, and neutralization procedures, irrespective of the chemistry of the ores currently being milled. The actual values of

TABLE 9-10
ESTIMATION OF LONG-TERM SEEPAGE QUALITY FROM KEY LAKE TAILINGS, BASED ON OBSERVATIONS, LEACH TESTS AND MODELLING

PARAMETER	RANGE	"BEST ESTIMATE"
pH (units)	3.5-8	5
TDS	2000-5000	3000
Ca	350-850	600
S04	1200-2000	1650
NH3	2-20	5
Na	20	10
Cl	20	10
Fe	0.01-5	3
Mg	0.5-5	5
As	<0.2-2	2
Si	<0.1-4.5	4
Al	0.1-0.7	0.5
Ni	<0.1-1.6	0.5
Co	<0.005-0.01	<0.01
K	8-15	10
Cu	0.01-0.05	0.05
Zn	<0.01-0.05	0.05
Ra226 (Bq/L)	10-55	50

* Process efficiency controlled. Soluble species such as NH3 and NaCl will not be present in significant concentrations in the long term.

TABLE 9-11
INTERMEDIATE STAGE SEEPAGE CHEMISTRY FOR RABBIT LAKE

PARAMETER	MEASURED RABBIT LAKE PORE WATER CHEMISTRY	INTERMEDIATE STAGE SEEPAGE "BEST ESTIMATE"
pH	5.0-8.5	7
TDS	6000-8000	7000
Ca	470	500
S04	6400	4500
NH3	350	<50
Na	155	20
Cl	210	20
Fe	0.25	1
Mg	960	20-500
As	<0.01	<0.1
Si	N/A	30
Al	N/A	30
Ni	0.4	1
Co	0.15	0.5
K	30	20
Cu	0.06	<0.1
Zn	0.06	<0.1
Ra226 (Bq/L)	<20	<10

* Leaching eventually by rainfall infiltration/snowmelt. Soluble species would be quickly diluted.

ammonia and magnesium being milled could cause some variation in sulphate solubility and hence sulphate values in the pore water (see Table 9-7).

The net result is that a "generic" composition for the seepage from tailings can be developed, together with "generic" compositions as the tailings evolve geochemically. Here, the presence of sulphides in the original ore become important in the way the pore water composition evolves.

In summary, four stages of pore water and seepage composition have been developed for ones where sulphides oxidize and three stages where they do not. When these stages have been defined, their long term interaction with natural barrier materials can be evaluated.

10.0 SOLUTE TRANSFER PROCESSES, TRANSFER RATES AND CHEMICAL STABILITY IN NATURAL BARRIER MATERIALS

This section of the report discusses the processes and rates involved when tailings seepage contacts and passes through natural barrier material and the effects on the chemical and physical properties of the barrier materials that result from such solute transfer. These barrier materials, till, silt, clay and peat, plus a specific modified soil, will be evaluated in their behavior with the four "generic" tailings seepage compositions developed earlier in this study.

It was anticipated that soils from each uranium producing area could be examined individually. The lack of adequate data, particularly on the geochemistry and mineralogy of the barrier materials described earlier, dictates that the general behavior of each material type be examined. The results can be applied to a particular area when sufficient data become available.

This section of the report incorporates:

- an evaluation of hydrogeochemical solute transfer processes in tailings seepage through natural barrier materials;
- the effects that such solute transfer processes and barrier attenuation properties have on the physical behavior of the barrier materials;
- the effects that solute transfer processes and barrier attenuation properties have on the chemical quality of the seepage passing through the barrier; and,
- an estimation of the rate of solute transfer in these materials as a result of the above processes and effects.

10.1 Hydrogeochemical Solute Transfer Processes

Detailed studies have been made of the hydrogeochemical changes in uranium tailings seepage waters during contaminant transport, particularly related to acidic tailings, for example Morin et al (1982); Dave et al (1982); Dubrovsky et al (1985).

As a result of such studies, a degree of agreement has been found between the hydrogeochemical behavior in acidic uranium tailings in both Canada and the United States. Reviews of the overall processes involved in these hydrogeochemical systems are given in Cherry et al (1982) and Shepherd and Brown (1984).

The principal processes affecting solute transfer which have been identified and which are relevant to barrier material behavior are given in Table 10-1, (modified from Cherry et al (1982) to incorporate potential effects), and include:

° **dissolution reactions:**	dissolution of calcite; dissolution of siderite;
° **replacement reactions:**	siderite for calcite;
° **precipitation reactions:**	precipitation of gypsum; precipitation of iron hydroxides; precipitation of aluminum hydroxides; precipitation of alumino-silicates; precipitation of alumite; precipitation of amorphous

TABLE 10-1
POTENTIAL GEOCHEMICAL PROCESSES FOR URANIUM TAILINGS SEEPAGE TRANSFER THROUGH NATURAL MATERIALS

PROCESS	REACTION	POTENTIAL EFFECT ON BARRIER MATERIAL	COMMENT
CALCIUM DISSOLUTION	CaCO3 + H+ --> Ca2+ + HCO3-	Removal of calcite from barrier matrix	If dolomite present, similar reaction possible
SIDERITE FORMATION	CaCO3 + Fe2+ --> FeCO3 + Ca2+	Replacement of mineral species: overall, no effect	Siderite does not occur in aerobic systems
SIDERITE DISSOLUTION	FeCO3 + H+ --> Fe2+ + HCO3-	Removal of secondary siderite from barrier matrix	Causes acid neutralization even when calcite is removed
GYPSUM PRECIPITATION	Ca2+ + SO42- --> CaSO4.2H20	Potential for precipitation in and blockage of pore spaces in barrier	Ca provided from calcite dissolution or ion exchange
IRON HYDROXIDE PRECIPITATION	4Fe2+ + O2 + 10H20 --> 4FE(OH)3 + 8H+	As for gypsum, but acid generating	Limited by the availability of oxygen in the system
ALUMINUM HYDROXIDE PRECIPITATION	Al3+ + 3H20 --> Al(OH)3+ + 3H+	As for iron hydroxides	Gibbsite or amorphous aluminum hydroxide
ALUMIOSILICATE PRECIPITATION	2Al3+ + H2O + 2H4 SiO4 --> Al2Si2O5(OH)4 +6H+	As for iron hydroxides	Formation of halloysite or similar aluminum salt
ALUNITE PRECIPITATION	K+ +3Al3+ + 2SO42- + 6H2O --> KAl3(SO4)2 (OH)6 + 6H+	As for iron hydroxides	Solubility constraint at low pH
AMORPHOUS SILICA PRECIPITATION	H4SiO°4 -->SiO2 (am) 2H20	Probably similar to gypsum	Solubility depends on major element chemistry
CATION EXCHANGE	H+ + M [solid] --> M+ + H[solid]	Decreases acid attack potential on barrier	H+ competes with major cations for exchange sites

silica; and,

- **ion exchange:** cation exchange removing hydrogen ions and reducing acidity and (probably) releasing sodium.

Reactions considered less important by Cherry et al (1982) include the formation of other sulphates, such as jarosite (K, Fe, $(SO_4)_2$, $(OH)_6$), which has been found to be significant in oxidizing environments (Dubrovsky et al, 1985).

Most of these reactions are invoked to explain the hydrogeochemical regime for the passage of acidic seepage through a neutralized tailings mass, calcite-bearing soil or a carbonate-bearing (bicarbonate) groundwater. Such reactions may not be relevant to the behavior of tailings seepage in contact with natural materials, after acid generation in the system ceases. Critical to many of the reactions, however, is the position of the water table, i.e. whether the reactions will occur in the aerobic, unsaturated vadoze zone, or in the almost anaerobic, saturated zone in the tailings mass.

In addition, once all pyrite has been oxidized, a significant proportion of the acid generation potential will be removed (the oxidation of other sulphides, or the oxidation of divalent ions to trivalent ions can also produce additional acidity), although this may take many decades. Some acid generation will continue from hydrolysis reactions with aluminum-bearing minerals, discussed by Dubrovsky et al (1985). This gives the basis for aluminum precipitation influenced seepage composition. On a longer time scale, perpetual leaching of tailings with low TDS, slightly acidic infiltration, generated by rainfall or snowmelt, will control the composition of pore water. In the latter cases, the following solution reactions could affect the behavior of the barrier materials in the longer term, due to re-solution of previously precipitated secondary minerals:

- re-solution of gypsum - controlled by the solubility of calcium sulphate (SO_4) about 1500 mg/L in pure water;
- re-solution of aluminum, hydroxides alumino-silicates alunite - probably very slow and controlled by the low solubility of alumite in water, in the presence of sulphates, and which may be pH and dependent; and,
- re-solution of silica - controlled by the equilibrium pH of the system, i.e. slow solution in acidic leaching over the long-term.

Based on the above description of potential hydrogeochemical reactions in uranium tailings seepage during transport, each barrier material type will be examined in terms of its reactions with the four generic tailings seepage stages in Section 10.2.

10.2 Chemical Effects on the Behavior of Natural Barrier Materials by Uranium Tailings Seepage

From development of four "generic" stages in the geochemical evolution of deposited uranium tailings, namely:

- the initial, process-controlled stage;
- the sulphide oxidation stage, when present;
- the re-solution stage; and,
- the long-term infiltration stage;

and, considering four possible natural barrier materials, namely:

- till;
- silt;
- clay; and,
- peat;

a matrix can be constructed and effects on barrier materials assessed. This is shown in Table 10-2. Each material type and the effects of seepage chemistry on its behavior will be discussed. A modified material type, sodium bentonite-amended soil, will be considered separately.

TILL

With the exception of one part of northern Saskatchewan where slightly acidic (pH 6) tills occur, the bulk of the tills in the uranium producing areas carry a small to large carbonate content (less than 1% in Saskatchewan to 25% in Ontario). Even in very small quantities, it has been demonstrated in several studies that the neutralization capacity of carbonates in soils to acidic tailings is large. Nasiakca et al (1981) and Crim et al (1979) demonstrate that even at low carbonate contents (0.02 to 0.4%), significant quantities of acidity were neutralized and the clay rich soils under test remained both neutral to alkaline in pH, and stable. Gee et al (1980) demonstrated that a 1 m compacted clay layer would have the capacity to neutralize at least 20 years of seepage of pH 2 to 2.5 from an uranium tailings impoundment in Wyoming. These data are supported by Peterson et al (1982) who demonstrated the stability of earth materials in acidic solutions and found the buffering capacity of the soils, due to small carbonate contents, resulted in a decrease in the permeability of the materials tested. Fundamentally, it would appear that the carbonate content of a barrier material may well control, in a chemical sense, the passage of uranium tailings seepage and its effects on the barrier. Accordingly, based on the available soil and mineral data from the main uranium producing areas in Canada, an "average" carbonate content of 0.5% has been assumed for the till material evaluated. In many cases, this value is significantly higher.

TABLE 10-2
ANTICIPATED EFFECTS OF SEEPAGE CHEMISTRY STAGE ON BARRIER MATERIALS

	Barrier Material			
Generic Tailings Seepage Chemistry Stage	Till*	Silt*	Clay**	Peat
STAGE 1: Initial Stage: high pH, Ca SO4 (neutralized), tailings seepage Duration - up to the operational life of impoundment	pH changes to 7-8. Possibility of increased solution of sulphate. Little precipitation of aluminum. No significant effect on barrier.	pH changes to 7-8. Possibility of increased solution of sulphate. No effect on barrier if clay mineral is illite or calcium bearing. If Na clay, ion exchange with Ca2+ cause shrinkage and increased permeability.	If sodium clay minerals, ion exchange of Na+ by Ca2+ with gypsum saturated solution would cause shrinking in clay and hence increase permeability. Otherwise, no appreciable effect.	pH of seepage reduced by natural pH of peat (about pH 3-5). No precipitation and probably no change in physical behaviour of barrier.
Stage 2: Sulphide Oxidation Stage: low pH2 (acidic), high TDS tailings seepage for sulphide-bearing tailings Duration - up to 200 yrs	Reaction with carbonate, during solution, but this precipitates gypsum in pore spaces; if aerobic, iron and aluminum precipitation. If anaerobic, no Fe: Al precipitation, net effect is reduced permeability.	As for till, but potential for long-term degradation of clay minerals to Al and Si in acidic environment, could cause increase in permeability.	Sodium clay - replacement of Na+ with H+, but little change in barrier permeability. Calcium clay - removal of Ca2+, replace with H+ and increasing permeability. If clay carries carbonate, neutralization produces precipitation in pore spaces and reduces permeability.	Peat leached by acidic seepage. Removal of some soluble constituents. Anaerobic reduction could cause further iron solution. Little effect on barrier, perhaps marginal increase in permeability.
Stage 3: Re-solution Stage: dominated by gypsum solution and either pH3-4 if oxidation stage 2 occurred (due to aluminum precipitation), or pH7 if no stage 2 occurred Duration - up to 400 yrs	If Stage 2, leaching of gypsum from pore spaces. Increased permeability. If no Stage 2, no effect.	If Stage 2 as for till and clay If no Stage 2 as for till and clay Tends to increase permeability	If Stage 2, little effect on clay minerals with possible further Ca2+ incorporation in clays. No further effect on barrier. If no Stage 2, solution of Ca2+ from clay. Gypsum saturation decreases in the long-term. Little change to barrier.	If Stage 2, pH increase to 3-4, possibly little Al precipitation causing slight decrease in permeability. If no Stage 2, pH of peat rises with infiltration, as pH of liquid drops. No effect on barrier.
Stage 4: Long-Term Leaching Stage: infiltration rainfall/snowmelt, low TDS water at pH5 Duration - +/- 10,000yrs	pH to 5. Slow solution of residual carbonates and marginal increase in permeability. Eventual decomposition of ancillary original mineral phases in barrier.	As for till and clay	pH changes to 5. Clay minerals reach equilibrium with infiltration, initially. Eventually decomposition of clays to Al and Si. Long-term weathering of barrier and increase in permeability.	pH changes to +/-5. No significant effect on peat behaviour.

* Behaviour function of carbonate content. Assuming 0.5 % CaCO3 content in till and 5 % clays in silt

** Behaviour may be more of a function of carbonate content, than clay mineralogy.

main uranium producing areas in Canada, an "average" carbonate content of 0.5% has been assumed for the till material evaluated. In many cases, this value is significantly higher.

The behavior of till materials in contact with the generic seepage compositions is considered below and summarized in Table 10-2.

- **Stage 1,** process controlled, high pH tailings seepage.

  The pH will drop to the range 7-8 with the possibility of increasing solution of sulphate. This may be accompanied by a little precipitation of aluminum, controlled by the gibbsite solubility low at about pH 6-7. Neither process is likely to have any significant impact on the physical behavior of the till.

- **Stage 2,** sulphide oxidation (if oxidizable sulphide minerals are present in the ore, e.g. Elliot Lake).

  As the sulphides oxidize, low pH (2) conditions are generated and carbonate in the barrier is dissolved releasing calcium ions. These react with the excess sulphate in the system and precipitate gypsum in the pore spaces of the till, causing blocking. Gypsum solubility is then the fundamental geochemical control on the system.

  If the system is aerobic, iron and aluminum as hydroxides, could precipitate. Substitution of siderite for calcite will have no significant effect in either aerobic or anaerobic conditions. There is unlikely to be any precipitation of iron in anaerobic conditions.

  The net result will be an overall blockage of pore spaces in either case but, perhaps, more so in aerobic conditions, and a decrease in the permeability of the barrier till.

- **Stage 3**, re-solution.

  If Stage 2 had occurred in the tailings, there would be a marginal rise in pH to 3 to 4, but, due to aluminum precipitation and the release of hydrogen ions in this process, the pH would not rise any further. With the cessation in the production of sulphate, gradual leaching and solution of the precipitated gypsum would occur through this stage until all the readily soluble precipitates were redissolved. This would increase the permeability of the till, as the pore spaces become free of gypsum (and other) precipitates. The effect of aluminum precipitation to counteract this material loss is unlikely to be large with the aluminum concentrations envisaged in the "generic" pore water composition.

  If the sulphide oxidation, Stage 2, did not occur in the tailings, the system pH would gradually decrease through pH 7 and the initial gypsum in the system (likely to be supersaturated) would come into equilibrium. This will have little or no effect on the behavior of the till. If there is any solution of calcium carbonate from the till, the excess sulphate in solution would cause gypsum precipitation. However, the gypsum saturation may be the overall control of calcium carbonate solubility.

- **Stage 4**, long-term leaching.

  Slow solution of the residual carbonates, where still present, will occur as the pH approaches that of rainwater (pH 5). This could cause a slight increase in permeability, if the carbonate contents were high (as, for example, in some of the Ontario tills). Eventually, there will be slow decomposition of the less stable, original mineral species in the till, leaving aluminum and silicon. In the case of both reactions, there is likely to be a small increase in permeability of the till over time, progressing very slowly.

SILT

The silt evaluated in this study is taken to have a carbonate content of 0.5%, the estimate for which was described above in the case of till. In addition, it is assumed that the silt will have small clay content (5% or less), based on the limited data available. The most common clay mineral appears to be illite, for the general case.

The reactions of the barrier silt to tailings seepage are summarized in Table 10.2. In detail, these are:

- **Stage 1**, process controlled, high pH seepage.

  This will tend to display similar behavior to the till, with a drop in pH and the possibility of increased sulphate solution. There will be no effect on the silt barrier material from either of these processes, or on the illite clay mineral. Illite, which may take part in ion exchange with the calcium, is a non-swelling clay mineral. If the clay mineral present were sodium bearing, ion exchange with the calcium-dominated seepage would cause shrinkage of the clay and, theoretically, an increase in the silt permeability. The amounts of clay present would determine the magnitude and significance of this effect. In general, if no sodium clay were present, the silt would be unaffected by this seepage.

- **Stage 2**, sulphide oxidation (if oxidizable sulphide minerals are present).

  The silt behavior is expected to be similar to that of till, i.e. a net blockage of pore spaces by gypsum precipitation and a decrease in silt permeability. In the acidic, pH 2 environment, there is the possibility of the long term degradation of the clay minerals present, presumably releasing aluminum and silicon. The levels in solution of aluminum would be controlled by aluminum sulphate (alumite) solubility, which is low, while the silicon may precipitate as amorphous silica. Depending on the clay mineral content of the silt, the overall effect of this decomposition would range from zero to further blockage of pore spaces, and decreasing permeability.

° **Stage 3**, re-solution.

In both alternatives, with or without a preceeding Stage 2, the net effects would be similar to till, with an increase in permeability as the in-pore precipitates are leached from the silt.

° **Stage 4**, long-term leaching.

Again, as for till, a very slow increase in permeability of the silt barrier would result over a long period of time.

CLAY

The magnitude of any effects on clay will depend on the total quantities of clay in the material mass and the type or types of clay mineral present. In this case, what might be assumed as the two extreme cases can be considered; calcium-rich clay minerals and sodium-rich clay minerals. Any non-swelling, non-shrinking clay minerals, such as illites, will be essentially unaffected by the tailings seepage, in terms of their physical response to reaction with the seepage.

From the summary in Table 10-2, the various stages are:

- **Stage 1**, process controlled high pH seepage.

  If the clay mineral is sodium rich, ion exchange, with the substitution of calcium for sodium in the clay lattice, will cause shrinkage of the clay minerals and an increase in permeability of the clay overall. Depending on the total clay mineral content, this shrinkage could be substantial and would seriously affect the performance of the clay as a barrier material. With a calcium clay (and similar material, such as marl), there will be no affect on this barrier material.

- **Stage 2**, sulphide oxidation (if oxidizable sulphide minerals are present).

  If sodium clay minerals are still present after Stage 1, the sodium ions will be replaced by hydrogen ions. Previous work (Peterson et al, 1982) suggests that this will not change the nature of the clay, in terms of particle size, to any great extent. Hence, there will be no change in the barrier permeability.

  If the soil were a calcium clay, there is the possibility for replacement of calcium by hydrogen ions. This might cause swelling of the clay and a decrease in permeability. However, if this swelling were large, it might cause heave in the clay barrier which, depending on the barrier plasticity, could conceivably cause failure. The likelihood of such behavior is not known and would require investigation.

  If the clay contains carbonates, as is likely in the latter case of soils examined in this study, neutralization of acid would occur releasing calcium ions which would react with available sulphate to give gypsum precipitation. Plugging of intergranular pore spaces (clays typically have 50% porosity) would occur and the permeability would decrease.

° **Stage 3**, re-solution.

Regardless of whether or not there was a preceeding Stage 2, the general process of removal of precipitates where formed, the leaching of carbonates and the degradation of clays would result in a gradual, but slow, increase in clay permeability.

° **Stage 4**, long-term leaching.

The response would be very similar to that of both till and silt, with a more enhanced possibility of the long-term degradation of the clays. A higher clay content would magnify the effects of the change, although they would be over a very long period of time.

PEAT

The fourth natural material included in this study presents a different type of behavior than the three other materials considered. This is due to the other materials considered. This is due to the fact that it is inherently acidic, pH 3 to 5, and is organic. The four stages in tailings seepage evolution produce the effects discussed below and summarized in Table 10-2.

° **Stage 1**, process controlled, high pH seepage.

The pH will gradually reduce, with the rate depending on the relative volume of seepage to peat. There is unlikely to be any precipitation of significance in the peat with a drop in pH (aluminum may be an exception), and the possibility of leaching would be small, as the peat will be well leached at its natural pH. No change in the behavior of the peat is expected.

- **Stage 2,** sulphide oxidation (if oxidizable sulphide minerals are present).

  Some leaching of the peat at pH 2 is possible, which may cause the removal of soluble constituents. The total effect is likely to be small. The effect on the decomposition of organic material present (i.e. increased rate) is not known. Anaerobic reduction of the seepage by the peat could enhance the solubility of species whose solubility is redox-controlled (e.g. iron). Little effect on the peat permeability would be expected. This tends to be confirmed in the studies made on the peat layers under tailings at Elliot Lake by, for example, Morin (1985).

- **Stage 3,** re-solution.

  If Stage 2 occurred, then a marginal increase to pH 3 to 5 would occur during this phase, with the possibility of slight aluminum precipitation. Depending on the aluminum concentrations, this could cause pore space blocking. However, at the perceived "generic" concentrations controlled by aluminum sulphate (alunite) solubility, this effect is predicted to be small.

  If Stage 2 were absent, there could be a marginal rise in pH with infiltration, but this could be compensated by organic decay. There should be no effect on the peat barrier material.

- **Stage 4,** long term leaching.

  At pH 5, there is expected to be no effect on the behavior of the peat during this phase. The only effects on the peat would be natural decomposition, which may occur in response to a change, in the redox state of the system.

AMENDED NATURAL MATERIALS

While not addressed directly in the foregoing discussions, the possibility of adding amendments to natural materials is often considered to form a barrier or liner prior to tailings deposition. One of the most used additives is sodium bentonite clay and the expected effect on bentonite of this type will be discussed.

It is not necessary to consider the response of a bentonite amended material by stage, as has been the case for the four natural materials. Consideration of the anticipated behavior of sodium clays, discussed in Section 10.3, indicates that shrinkage in the structure of the sodium clay would occur when a calcium-bearing solution was in contact with the clay. The calcium-rich initial tailings seepage is expected to cause substitution of calcium for sodium in the structure of the bentonite and, hence, shrinkage. In this case the effectiveness of the additive, its swelling capability in the presence of water, may be lost and the barrier or liner would fail. Sodium-bearing additives are unlikely, therefore, to be successful by themselves in preventing calcium rich, neutralized tailings seepage in the long term. Any long term effectiveness of sodium clay additives may not accrue from its swelling nature but rather permeability reductions resulting from gradation improvement of the parent soil.

10.3 Attenuation Properties of the Barrier Materials

The contaminant attentuation properties of natural materials, similar to the natural barrier materials being considered here under conditions of uranium tailings seepage, have been widely reported and the reactions have been documented (Cherry el at, 1982) for varying conditions.

Using these published data, the possible attenuation mechanisms that will effect seepage quality evaluated above can be established. In addition, the chemical properties of the tailings seepage during the four generic pore water stages are defined, and the physical and chemical nature of the barrier materials and how these characteristics will change as seepage from each stage occurs is also established. Therefore, it is possible to evaluate the attentuation mechanisms that will occur and predict the effect on the quality as seepage moves through the barriers and exits into the environment. In each case, however, it must be remembered that the total attenuation capability of the system will be a function of the contaminant mass in the seepage water, and the thickness (i.e. mass) of the barrier material. Therefore, the thicker the barrier, the greater the potential attenuation capacity.

From Section 9.0, it can be seen that the constituents of the neutralized tailings pore water which can be considered to be environmentally sensitive species and represent the contaminant potential source can be placed in groups of similar chemical behavior, thereby facilitating this discussion. These groups are:

- Major cations and anions such as (TDS) Ca, Mg, Na, K, SO_4 and Cl;
- Transition and heavy metals such as Co, Ni, Cr, Zn, Cu, Fe, Al and Mn;
- Amphoteric metals including As, Mo and U;
- Other metals such as Pb and Ba; and,
- Radionuclides, especially Th_{230} and Ra_{226}.

The attenuation potential and the attenuation mechanisms which could effect the concentration of these groups in the natural barriers are discussed below.

MAJOR ANIONS AND CATIONS

This group provides essentially all of the TDS content of the pore water. In general, it can be stated that little attenuation of this group is possible, except that provided by the precipitation of gypsum or if clay minerals are present.

Gypsum precipitation will control the concentration of calcium and sulphate to the extent that the supply of either is limited to equilibrium concentrations (Ca, 400 mg/L; and SO_4, 1,500 mg/L). Sulphate concentrations could also be reduced by the precipitation of Pb or Ba sulphate but the quantities of these two heavy metals are so low as to make this an unimportant attentuation possibility in terms of sulphate loads. If clay minerals are present, ion exchange can occur. Given the calcium concentration in the tailings seepage, substitution will remove calcium from the solution, releasing sodium if sodium clays are present.

However, it is the reaction of acidic pore water (Stage 2 generic composition) with calcium carbonate in the barrier materials, and the freeing of calcium into solution to combine with sulphate and precipitate gypsum, that effectively controls the rate of movement of the acidic front and the bulk of environmentally sensitive species through the barrier materials. This represents the most significant control on solute transfer rates.

TRANSITION METALS

These species have the potential to be attenuated by the barrier material by several mechanisms. While concentrations of these elements are very low due to neutralization of the tailings prior to discharge and the formation of precipitates (one of the principal attenuation mechanisms in nature), if the sulphide oxidation stage occurs in the tailings, then significant remobilization of these elements will occur. However, if carbonate minerals are present in the barrier material, the pore water will be neutralized and precipitation of these species will once again occur. In addition, these transition elements will compete very effectively for the cation exchange sites that exist on the clay minerals present in the silt and clay barrier materials.

Surface absorption mechanisms, less well defined than clay exchange capacity, will also act to remove these transitional metals from seepage. This mechanism can operate for all barriers. Amorphous iron oxyhydroxides likely present in the natural till, silt, clay minerals and the organic matter in the peat, all demonstrate the effect of surface adsorption and capabilities for removal of trace metals.

AMPHOTERIC METALS

Arsenic and molybdenum will form anionic complexes which provide mobility, even when other metals precipitate upon neutralization or are removed by cation exchange or surface absorption.

Arsenic concentrations can be reduced by precipitation as calcium, ferric or barium arsenate. This process is employed, as discussed in Section 9, as part of the process to control arsenic in the tailings effluent. Therefore, it can be concluded that the arsenic concentrations in the process controlled pore water of 1 ppm will not be reduced by barrier related attenuation mechanisms. In the case of the Key Lake type of ore (high As), the neutralization of the tailings and the addition of iron sulphate to precipitate ferric arsenate assume importance if the barrier materials are deficient in available iron or calcium.

The low concentration of molybdenum, also 1 ppm, will also not be reduced as solute is transported through the barrier.

HEAVY METALS

Both barium and lead, which are at very low concentrations in the process controlled pore water due to the low solubility of their sulphate salts, will not likely undergo further attenuation in the barriers. Cationic ion exchange or surface absorption may remove further amounts of Pb, but even if these mechanisms do not act, the very low concentrations that exist in seepage do not appear to pose any environmental concern.

If the sulphide oxidation stage occurs, SO_4 concentrations will continue to control Ba and Pb concentrations at the levels that exist in the process controlled pore water.

RADIONUCLIDES

Neutralization has proven to be a reasonably effective mechanism for removing Th_{230} from solution as demonstrated by the analysis provided in Table 9.4. Precipitation of Ra_{226} with barium chloride is the accepted means of controlling Ra_{226} concentrations in mill and mine effluents. This procedure is used at all mills. While Ra_{226} concentrations may increase slightly in tailings under low pH conditions over time due to further dissolution of the uranium ores, control of Ra_{226} by barium sulphate co-precipitation will continue. If the pore water re-acidified due to sulphide oxidation, precipitated Th_{230} could be brought back into solution. In this case, neutralization of pore water seepage in the barrier and, therefore, re-precipitation of Th_{230} would reduce solute transport. It has been demonstrated that Ra_{226}, and other radionuclides, can co-precipitate with gypsum and this will assist in their removal in Stage 2 type pore waters.

With respect to the barrier materials themselves, Table 10-3 summarizes the attenuation mechanisms possible for each material and indicates the mechanisms that will operate under the different pore water seepage stages. As shown,

TABLE 10-3
POSSIBLE BARRIER ATTENUATION MECHANISMS

	TILL	SILT	CLAY	PEAT
1. Attenuation Mechanisms Possible	-Surface absorbtion of acid seepage -Neutralization, if CO3 minerals present -Precipitation -Co-precipitation	-Cation exchange due to clays present -Surface absorbtion of acid seepage -Neutralization, if CO3 minerals present -Precipitation -Co-precipitation	-Cation exchange -Surface absorbtion of acid seepage -Neutralization, if CO3 minerals present -Precipitation -Co-precipitation	-Surface absorbtion
2. Effective mechanisms in different seepage stages	TILL	SILT	CLAY	PEAT
Stage 1: Process Controlled	-Surface absorbtion	-Cation exchange -Surface absorbtion	-Cation exchange -Surface absorbtion	-Surface absorbtion
Stage 2: Sulphide Oxidation	-Surface absorbtion -Neutralization -Co-precipitation	-Cation exchange -Surface absorbtion -Neutralization, if -Co-precipitation	-Cation exchange -Surface absorbtion -Neutralization -Co-precipitation	-Surface absorbtion
Stage 3: Re-solution	-Surface absorbtion	-Cation exchange -Surface absorbtion	-Cation exchange -Surface absorbtion	-Surface absorbtion
Stage 4: Infiltration Long-Term	-Surface absorbtion	-Cation exchange -Surface absorbtion	-Cation exchange -Surface absorbtion	-Surface absorbtion

neutralization of acid seepage during the sulphide oxidation seepage stage is the most important attenuation mechanism. Whether it occurs or not depends on the presence of carbonate minerals in the barrier. If these do not exist, or not in sufficient quantity, and sulphide oxidation occurs, significant quantities of potential contaminants could move into the environment. Surface absorption and cation exchange mechanisms will operate regardless of the pore water seepage stage, but their effectiveness can only be determined based on specific information about the properties of the barrier material and the chemical composition of the seepage at any particular time. While peat provides the least amount of geochemical attenuation potential of the four materials considered, it is known to have considerable capacity to concentrate radionuclides, probably through absorption mechanisms. Based on its behaviour in nature, this may give peat attentuative capacities comparable (or even in excess of) to capacities of clay soils.

10.4 Solute Transfer Rates Through Barrier Materials

The transfer rate of solute through natural barriers must be evaluated with respect to the nature of the solute. Conservative solute species, such as the major anions and cations, will move at essentially the same rate as the pore water. Dispersion and diffusion can increase the apparent velocity of these constituents (Freeze and Cherry, 1979), but, in essence, the rate of movement is essentially the same as that of the pore water.

Solute elements that undergo attenuation, either by surface mechanisms or as a result of neutralization, precipitation or co-precipitation, move at a slower rate than the pore water. Prediction of the effect of attenuation in retarding the movement of solutes can be made using the distribution coefficient concept (Freeze and Cherry, 1979). However, this concept and the means to quantify retardation of solute transport has come under criticism in recent years (Cherry et al, 1981).

In addition, bulk solute transport can be controlled by chemical reactions, such as neutralization, which could occur in the cases under consideration in this study. As acid seepage contacts a barrier with carbonate mineralization, such reactions will occur. In investigations conducted at several uranium tailings sites, the relative rate of advance of the acidic part of the seepage as compared with the seepage velocity has been estimated, i.e. the rate of solute transfer with respect to flow. The rate of solute transfer is shown to be conditioned by the chemical influence of the subsurface soils or natural barrier materials. A collation of data by Cherry et al (1982) from 3 uranium tailings impoundments shows the relative rate of solute transfer for an acidic contaminant plume as compared to the seepage velocity to be between 8% and 40%. One further case indicates seepage acid plume velocities are the same. Clearly, the actual rate of advance will depend on the absolute barrier permeability. For example, studies at Elliot Lake indicate rates of advance of an acid front of 0.2 to 2 m/yr, i.e. less than 10^{-6} to 10^{-5} cm/sec, whereas seepage velocities must be of the order of 10^{-4} cm/sec or more.

In terms of chemical effect of tailings seepage on the barrier materials, the net result of blockage of pore spaces by precipitation, say of gypsum, could be two fold:

- permeability would decrease, hence reducing the mass flow of seepage water passing through the barrier.

- as permeability decreases, the hydraulic head would increase given a constant recharge value, hence, increasing the seepage velocity.

Overall, it would be anticipated that the reduction in mass loading would have a beneficial effect in reducing discharge of contaminants to the environment.

An additional effect of tailings seepage, described in Section 10.2, is the change in permeability induced by ion exchange, where calcium would substitute for sodium ions in clays causing shrinkage of the clay. The net effect will be an increase in permeability; such an increase can be by an order of magnitude at least. If the ion exchange process caused sufficient shrinkage to induce cracking of the clay, the effect on permeability would be much greater. Solute transfer rates could be significantly increased, therefore, if such an ion exchange process were to occur with a clay barrier material. (It should be noted that gypsum is used in agricultural practice as a soil amendment to sodium rich soils to improve their drainage, through the process of ion exchange.)

11.0 PHYSICAL STABILITY OF NATURAL MATERIAL

11.1 General

Permeability is a primary factor in the determination of the suitability of natural materials as barriers for waterborne contaminants. Increases in permeability can arise due to an increase in void ratio (defined as the ratio of the volume of voids between soil particles to the volume of solid particles); the development of cracks or joints (termed the secondary structure of soil); and, piping, a process of soil erosion by seepage.

An increase in the void ratio of a soil is due generally to a decrease in the effective stress between soil properties. A decrease in effective stress can result from removal of overburden and or a rise in the water table, or an increase in the soil water content. In general, the swelling behavior of soil can be related to a simple index test such as Atterberg Limits; a high plasticity index is indicative of a high clay content and a high potential for swelling. The amount of swelling that could take place in a soil is measured in the oedometer test.

High plasticity soils may swell sufficiently to increase the void ratio (and water content) by 15 percent or more. Since permeability is a function of pore size (i.e. void ratio), swelling would increase permeability.

11.2 Shrink-Swell

The amount of shrinkage and swelling the soil undergoes upon drying or wetting is a function of the amount and type of clay minerals present in the soil. Clay minerals of the expanding lattice type, such as montmorillonite, exhibit large volume changes when the moisture content of the soil changes. Illite, and to a lesser degree kaolinite, is more stable and shows much reduced volume change with changes in soil water content. The available data indicate the predominant clay minerals in the study areas are illite and kaolinite with no montmorillonite identified. Only small amounts of any clay minerals are present. Thus, the shrink or swell potential of the natural materials is very low. Therefore, natural materials used in barrier construction would be expected to show little change in void ratio (or permeability) because of shrinkage or swelling characteristics. By comparison, natural soils stabilized with commercial bentonite may be subject to significant volume change attributable to the behavior of the montmorillonitic clay minerals.

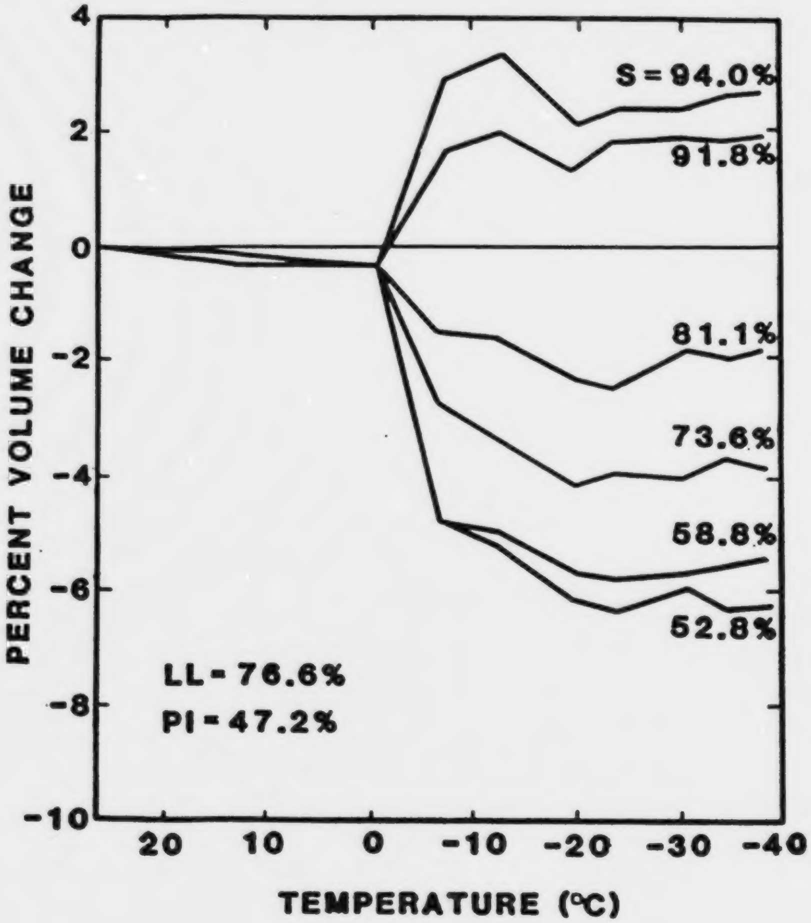
11.3 Cold Temperature Volume Change

Cold temperature volume change is comprised of two components:

- A volume increase due to expansion of the water phase and ice segregation; or,
- A decrease in volume due to thermal contraction of the mass.

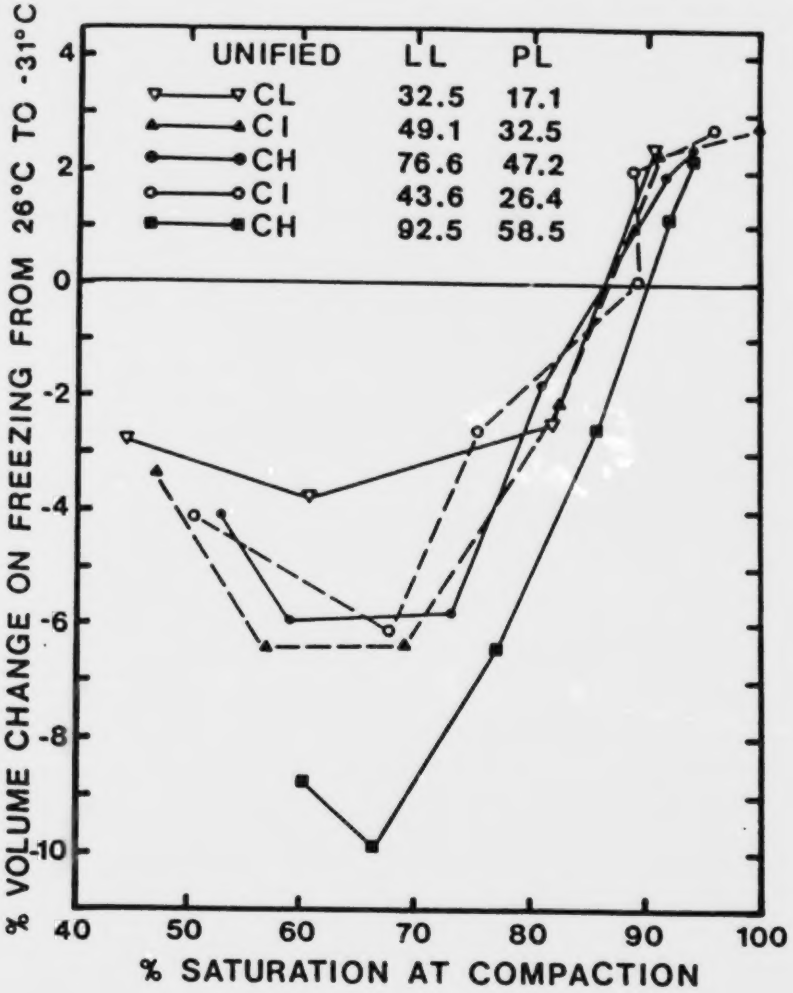
A decrease in volume is of particular concern since it will create fissuring and fracturing, resulting in an increase in permeability. Hamilton (1966) measured the volume changes of samples of compacted clay and till as the temperature of the samples was lowered to -38°C. The results of these tests, illustrated in Figures 11-1 and 11-2 indicate that in all cases where samples were frozen at less than above 85 percent saturation, the soils decreased in volume upon freezing. However, samples frozen at more than about 85 percent saturation increased in volume.

The relationship between the volume change and degree of saturation is illustrated in Figure 11-2. Since most materials are placed dry of optimum, most natural liners in northern Canadian climates can be expected to experience net shrinkage upon freezing, leading to a dramatic increase in permeability. Similarly, if natural liners are placed without adequate frost



VOLUME CHANGE TEMPERATURE PLOTS FOR CLAY
(HAMILTON, 1966)

FIGURE 11-1



VOLUME CHANGE VS SATURATION
FOR COMPACTED CLAYS

FIGURE 11-2

protection, there is a risk of cracking on freezing, leading to an increase in liner permeability.

11.4 Thaw Consolidation

Virtually all of the soil in the uranium producing areas can be expected to exhibit ice segregation upon freezing. Casagrande (1932) stated that: "Under natural freezing conditions, and with a sufficient water supply, one should expect considerable ice segregation in non-uniform soils containing more than 3 percent of grains smaller than 0.02 mm and in very uniform soils containing more than 10 percent smaller than 0.02 mm." As a rule of thumb, soils containing more than 5 to 10 percent of grains smaller than 75 um are generally regarded as frost susceptible. Thus, with the exception of clean medium to coarse grained sand, virtually all of the soils within the uranium producing areas are expected to be frost susceptible and will exhibit strong ice segregation.

The soils will exhibit a significant increase in void ratio as ice segregation occurs. Redensification (consolidation) of the soil does not take place immediately upon thawing. Thus, there is a period of elevated void ratio and permeability immediately following thawing of the ice. Permeability will be temporarily elevated, falling with subsequent consolidation.

11.5 Piping

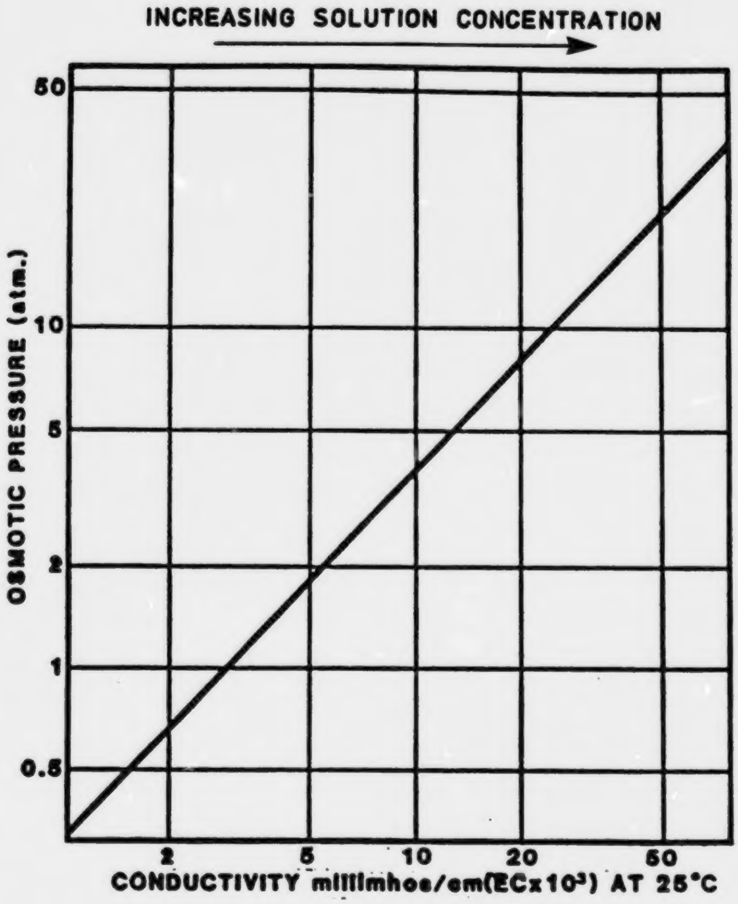
Piping is a phenomena that is associated with seepage of groundwater through soils where the gradient is higher than the critical gradient. At the critical gradient, soil particles are displaced by seepage forces. The result is increased permeability and elevated gradients. As more soil particles are removed, the gradients continue to increase until an open seepage path is created and failure results. Filter criteria have been established setting gradational criteria for adjoining soil layers to prevent the movement of fines from one to the other. This is of particular significance where modified soil liners are constructed on relatively coarse and open graded soils. To prevent piping of fines and failure of the liners, the gradation of the liner and the gradation of the parent soils must obey the filter criteria.

11.6 Osmotic Consolidation

Consolidation is normally perceived to take place under the external application of stress such as a fill or foundation load. However, it is well known that concentrated solutions can also exert significant effective stress as illustrated in Figure 11-3. This figure illustrates that concentrated leachates can exert several atmospheres of osmotic pressure, drawing pore water from the soil. These phenomena have been exhibited in laboratory experiments and observed in the field. They are of particular interest in clay soils where a clay mixed with fresh water is exposed to a more concentrated leachate. The result may be significant shrinkage leading to cracking and leakage of soil barriers. The shrinkage will be greater for active (montmorillonitic) clays molded using fresh water to moisture contents above the plastic limit, and subjected to concentrated leachates. Bentonite slurries mixed with fresh water could be expected to undergo very high shrinkage when exposed to concentrated leachates. The amount of shrinkage can be reduced by using the leachate as molding water and reducing the placement water content.

11.7 Soil Modification

Soil modification refers to changing the physical characteristics of the soil to improve its strength, compressibility or permeability characteristics. Permeability is a primary consideration in barrier construction. The permeabilty is reduced by:



OSMOTIC PRESSURE OF SATURATION EXTRACTS
OF SOILS AS RELATED TO ELECTRICAL CONDUCTIVITY

FIGURE 11-3

- Reducing the void ratio, or
- Plugging the pores.

The void ratio may be reduced by:

- Compaction or consolidation; or,
- Improving the gradation.

Compaction is of little practical value in reducing the permeability in the soils found in the uranium producing areas in Canada. While the coefficient of hydraulic conductivity may be reduced by two or three orders of magnitude, the reduction is not sufficient to allow the lean and coarse grained soils found in these areas to be used as a barrier. With the exception of the silt till at Elliot Lake, only minor amounts of suitable fine grained materials were identified; even these materials in a highly compacted state would have a coefficient of hydraulic conductivity only marginally acceptable as a seepage barrier. Further, there is not conclusive evidence that compacted soils will retain their density and hence their low permeability. In fact, considerations (freezing - thawing, desiccation and osmotic consolidation) discussed above suggests that this initial density will be lost unless protection against these factors is provided. As a result, permeability reduction by compaction alone is not adequate for the barrier materials identified in the uranium producing areas.

Compaction combined with gradation improvement can provide a significant and more durable decrease in permeability. Seepage through properly placed clay barriers occurs through the pores. The rate of seepage (coefficient of permeability) varies approximately as the square of the mean pore diameter. It is generally accepted that the mean pore diameter is controlled by the grain size diameter of the D_{10} fraction. Thus, adding a small amount of fines can significantly reduce the effective pore diameter, markedly reducing effective hydraulic conductivity. Permeability is a function of porosity as well as effective pore diameter. Porosity is governed by compaction and gradation. A perfectly graded material would have only a small percentage of voids. A poorly graded material has a large void volume. Incorporation of fine (silt and clay size) particles into the poorly graded materials commonly found in the uranium producing areas will reduce the volume of voids, thereby reducing permeability. This can be accomplished by mixing natural materials (silt or clay) or by adding materials such as commercial bentonite. Natural fines in the uranium producing areas are generally non-swelling, physically and chemically stable rock flour clastics, suitable for blending with other soils to reduce permeability.

Commercial bentonite is produced by grinding a naturally occurring clay, principally sodium montmorillonite, and treating it with reagents to ensure sodium saturation of the clay mineral and to enhance its water holding capacity. The resulting clay can adsorb water equivalent to more than 600 percent of its dry weight, and will swell to a volume of more than ten times its dry volume in a free swell condition. The product can be purchased in ground or granular form for mixing with soil as a dry powder or as a slurry. Its water holding and swelling properties make it a useful low permeability sealant for some containment applications.

Commercial bentonite has been used to reduce the permeability of natural soils used in construction of tailings management facilities at Cluff Lake and Key Lake in northern Saskatchewan. Two different kinds of barriers were constructed in northern Saskatchewan: a slurry trench barrier; and, compacted soil-bentonite barriers at both Cluff Lake and Key Lake.

The compacted soil-bentonite barriers were constructed by mixing bentonite with till. The Cluff Lake till contained from 8 to 20 percent fines (silt and clay sized particles) and was mixed with 4 to 5 percent dry bentonite by dry weight of soil to give an average coefficient of permeability of less than 1 x

10^{-8} m/sec. The design specified using the minus 100 mm fraction of the till and mixing it with at least 4 percent bentonite by dry weight of soil. The soil-bentonite mixture was compacted in lifts not exceeding 300 mm thick to at least 95 percent of maximum modified proctor dry density. The barrier had a minimum thickness of 1.5 m measured perpendicular to the slope and protected with 2.5 m of earth cover. Field mixing was accomplished utilizing a rotary mixer. Typical gradation curves for parent soil and the soil-bentonite mixture are given in Figure 5-8.

The borrow source for construction of the soil-bentonite barrier at Key Lake was a well graded till with from 0 to 15 percent finer than 75 um. The barrier was constructed in 200 mm lifts, first removing all particles larger than 100 mm in diameter. Bentonite was distributed on the surface at a rate varying between 8 and 16 kg/m^2 and mixed into the soil with a rotary mixer. The amount of bentonite added was generally in the range of 3 to 4 percent by dry weight of soil. Water was added to bring the molding water content to approximately 10 percent and the conditioned mixture compacted with a specified number of roller passes that resulted in an in place density of approximately 100 percent of maximum modified AASHO dry density.

Construction procedures used on the soil-bentonite cutoff wall at Cluff Lake are documented by Geocon Ltd. (1980c). Till borrow with from 10 to 25 percent, by dry weight, finer than 75 um was used to mix with bentonite slurry to produce a cutoff with a coeffficient of hydraulic conductivity of less than 1 x 10^{-9} m/sec. The construction was accomplished by excavating a trench 1.1 m wide using a backhoe and filling the trench with a bentonite slurry containing approximately 13 percent bentonite by weight. The bentonite slurry and till borrow were mixed on a working platform to produce a uniform slurry with a specified slump between 50 and 150 mm. The actual test results varied between 250 and 159 mm with an average of 81 mm. The water content of the soil-bentonite slurry backfill varied between 9.1 and 21.7 percent with an average value of 14.5 percent. Initial mixing of the bentonite slurry and till resulted in a measured permeability slightly higher than the specified value. Additional bentonite was added to raise the total bentonite content to approximately 4 to 5 percent by weight. The resulting slurry was bulldozed into the trench, displacing the bentonite slurry. The resulting construction was carefully sounded and inspected to ensure the required threshold permeabilties were achieved.

Some experiments (Clifton Associates Ltd., 1978; Saskatchewan Mining Development Corporation, 1985) have attempted to reduce void ratio by incorporating peat. These experiments in large part have not been successful when up to 20 percent peat by dry weight of soil was incorporated in a uniform sand. It therefore appears likely that the most beneficial use of peat would be in a compressible layer where the permeability would reduce with time.

Permeability can be reduced by plugging soil voids. The most commonly used materials are Portland cement, fly ash and asphalt. The materials in the uranium producing areas are suitable for production of soil cement which is manufactured in situ by incorporating from 4 to 6 percent of Portland cement into natural soils of the proper gradation. The resulting soil cement has relatively low intergranular permeabilty but is subject to extensive cold weather cracking and, therefore, large secondary permeability. The cementing materials may also be subject to slow solution by leachate, leaving them more permeable in the long term.

Fly ash shows some promise as a permeability reducing agent, particularly when used in conjunction with bentonite. Fly ash exhibits some pozzolanic (cementing) action in lime rich soil. This action will produce alumina-silicates which plug void spaces. However, these mixtures show similar properties to soil-cement mixtures.

Asphalt is commonly used to plug soil voids. It is routinely used in road paving but has had limited use in waste management schemes in Canada. Its chemistry, and therefore its thermo-mechanical properties, can be controlled during manufacture. It is relatively inert when buried, and should be resistant to attack from chemicals normally utilized in uranium milling processes. From 4 to 7 percent asphalt by dry weight of soil can be field incorporated into the poorly graded lean soils identified in the uranium areas. Construction technology is readily available using techniques commonly applied to highway construction. The resulting modified and compacted soil mass can be reduced to essentially zero air voids, giving a low permeability, ductile barrier. While it appears the material is physically and chemically stable, there is some evidence that it may suffer long term attack by bacteria.

The properties of the natural soils can be modified to make them more suitable as barriers to seepage and contaminant migration. However, mechanical weathering is a major problem and can severely damage carefully constructed barriers. Therefore, it is very important that adequate protection against the damaging influence whether heat, sunlight, frost or desiccation be provided. Covering with soil to the required depth will provide the most economical protection. A few millimetres of soil cover is adequate to protect against ultraviolet light, but in excess of 3 metres of cover may be required to provide adequate frost protection in northern Saskatchewan.

12.0 EXTENSION OF FINDINGS TO OTHER AREAS

One of the objectives of this study is to extend the findings on the behavior of natural barrier from currently producing areas of uranium development in Canada. The process used earlier in this report described how seepage compositions were derived for various producing areas and a generic pore water composition formulated. For potential and possible areas, it is wise to repeat this process to ensure they can be considered in similar fashion. This section of the report, therefore, discusses the extension evaluation.

To make the comparison between present and potential uranium producing areas, the following procedure was followed:

- "potential" and "possible" areas of uranium production have been identified;

- ore type and potential ore processes for each area have been estimated and compared to the current producing areas;

- the general nature of the tailings pore water and seepage quality was estimated considering ore characteristics and milling processes;

- mineralogical and geochemical differences in the potential areas for the current producers are assessed in so far as they may affect reaction mechanisms and transfer rates in the natural barrier materials.

The potential and possible uranium producing areas were identified in Section 2.

12.1 Ore Mineralogy

Potential Producers

Table 12-1 gives a summary of the general ore mineralogy for the potential uranium producing areas in northern Saskatchewan. In general, the ores are essentially similar, with little variation on the uraninite/coffinite/pitchblende uranium mineralogy. In all cases, except the Collins Bay-Eagle Zone, nickel and/or cobalt arsenides are present, together with a variety of gangue minerals. This makes these areas similar to the Key Lake ore discussed earlier and it is suggested that they can be considered as such from a mineralogical point of view.

The Collins Bay-Eagle Zone does not carry nickel arsenides, as the other potential area ores. It appears, therefore, to be more like the original Rabbit Lake ore discussed earlier, except that it has a much higher grade.

Possible Producers

Some data are available on the uranium and associated mineralogy of the possible producing areas; these are given in Table 12-2

While the Lone Gull deposit bears a similar uranium mineralogy to the northern Saskatchewan deposits in general, it does not carry nickel and/or cobalt arsenides or sulphides, making it more like the overall mineralogy of the Collins Bay-Eagle Zone and the original Rabbit Lake ore.

The other two possible producing areas are anomalous with respect to Canadian uranium deposits. The Blizzard deposit in British Columbia has its uranium in the form of calcium and magnesium uranyl phosphates, and this may necessitate a different processing technology than for the more usual Canadian ores. The Laborador, Kitts/Michelin deposits have pitchblende as its uranium mineral,

TABLE 12-1
COMPARISON OF MINERALOGY FOR POTENTIAL URANIUM PRODUCING AREAS
NORTHERN SASKATCHEWAN ORES: PRINCIPAL COMPONENTS CNLY

	CIGAR LAKE	MIDWEST LAKE	DAWN LAKE	MCCLEAN LAKE	A-ZONE	COLLINS BAY D-ZONE	EAGLE ZONE
ORE MINERALS	Uranite Pitchblende (minor coffinite)	Pitchblende Coffinite	Pitchblende Coffinite Uraninite	Coffinite Pararammelsbergite Uraninite	Pitchblende	?	Pitchblende (massive)
GANGUE	Ni/Co Sulfo arsenides, eg. gersdorffite, niccolite, cobaltite, plus some minor sulphides	Minor sulphides, eg. chalcopyrite, cobalt minerals & silicates, kaolinitic/sericitic clay with chlorite	Ni-arsenides, geothite (fe), carbonates, quartz, illite, chlorite, sericite & Ti minerals	Sulphides including pyrite, chlorite, siderite, illite, arsenides in a clay matrix	Ni/Co arsenides in clay, clayey-sand or sand host	Ni arsenides in clay rich sandstone	*NB

* No Ni arsenides present in Eagle Zone ore

TABLE 12-2
COMPARISON OF MINERALOGY FOR POSSIBLE URANIUM PRODUCING AREAS:
Principal Species Only

	LONE GULL NWT	BLIZZARD BRITISH COLUMBIA	KITTS/MICHELIN LABRADOR
ORE MINERALS	Pitchblende Coffinite (minor uranophane)	Autunite, Salenite*	Pitchblende
GANGUE MINERALS	Quartz, sericite, illite, chlorite, sulphides including pyrite, chalcopyrite, marcasite	Quartz, feldspar, chlorite, micas	Calcite, fluorite and sulphides

* Calcium and magnesium uranyl phosphates

which is the same as many other Canadian ores. However, the mineralization is associated with carbonates, principally calcite, and this may affect the method of uranium extraction/recovery.

12.2 Ore Chemistry

Potential Producers

Some chemical data are available on the Cigar Lake ore and Midwest Lake ore. Although no typical analysis of the McClean mineralization is available, for the purpose of this study it can be presumed that it would be similar to the analysis of the Midwest ore, considering their similar mineralogical characteristics.

Chemical data for the Cigar Lake and Midwest Lake are given in Table 12-3. As with the format used for currently producing areas, chemical constituents are divided into those species which could impact on natural barrier materials, and those species which are potentially of enviromental concern.

While there are little data overall, the general analysis of both ores is similar to that for Key Lake type ore, although the Cigar Lake ore is a very high grade uranium ore compared with all other Canadian ores. Therefore, from a chemical viewpoint, it will be assumed that all of the northern Saskatchewan potential producers, with the exception of the Collins Bay Eagle Zone ore, can be considered the same in their ore chemistry and mineralogy as the Key Lake ore type.

Possible Producers

An analysis of the ore from the Lone Gull deposits, is available, although no data are apparently published from either the Blizzard or the Kitts/Michelin deposits. The Lone Gull analysis, given in Table 12-4, shows significant

TABLE 12-3
CHEMICAL ANALYSIS OF ORES FROM CIGAR LAKE AND MIDWEST LAKE

			CIGAR LAKE	MIDWEST LAKE
Major species which could impact barrier materials	Si02	%	-	76
	Fe	%	-	1.3
	S	%	-	1.1
	Al	%	-	3.2
	Ti	%	-	0.3
	CO3	%	-	0.5
	K	%	-	1.2
	U308	%	14.5	2.2
Environmentally sensitive species	Cu	mg/g	7000	1000
	Zn	mg/g	400	700
	Pb	mg/g	12,000.*	
	F	mg/g		500
	PO4	mg/g		600
	Ni	mg/g	10,000.*	17,000.*
	As	mg/g	17,000.*	32,000.*
	V	mg/g		800
	Co	mg/g	1500	2000
	Mo	mg/g	1400	600
	Ra226	Bq/g	1,450 (est)	275 (est)

* can be considered major species

TABLE 12-4
CHEMICAL ANALYSIS OF LONE GULL ORE

Major species which could impact barrier materials	Si02	%	60
	Fe	%	2.7
	Al	%	9.9
	S	%	0.1
	Ti02	%	0.5
	U308	%	0.75
	K	%	4.1
Environmentally sensitive species	Cu	mg/g	20
	Zn	mg/g	-
	Pb	mg/g	200
	Ni	mg/g	20
	As	mg/g	300
	V	mg/g	700
	Co	mg/g	30
	Mo	mg/g	200
	Ra226	Bq/g (est)	75

* can be considered major species

amounts of silicon, aluminum, potassium, magnesium and iron. Little arsenic, cobalt or sulphur are present. The general type of analysis is intermediate between the Key Lake and Rabbit Lake type ore.

12.3 Ore Processing

Potential Producers

With the relatively sparse data at hand, there is no compelling reason not to expect that the major features of the processing regimes for Key Lake ore will not be applied, in general terms, to the northern Saskatchewan ores (i.e. Cigar Lake, Midwest Lake, Dawn Lake and McClean Lake), with the exception of Collins Bay Eagle Zone.

From the previous discussion on current milling processes, this would involve the use of the following chemicals:

either

$H_2SO_4/O_2NH_3/NH_4OH$ plus $Ca(OH)_2$ or $Ca(OH)_2 + Fe_2(SO_4)_3$;

or,

$H_2SO_4/NaClO_3/H_2O_2$ plus $Ca(OH)_2$ or $Ca(OH)_2 + Fe_2(SO_4)_3$;

or, a combination of the above. By extrapolation, this would tend to produce a tailings similar to the Key Lake type of tailings. It might be expected that the high grade of the Cigar Lake ore may require process modifications, if only to modify the predicted high radioactivity. (It may be possible to extract the uranium from the Collins Bay-Eagle Zone ore by the same process as that being used currently for the Collins Bay-B-Zone, although the ore characteristics are somewhat different).

Possible Areas

By extension of the ore mineralogy and chemistry, it would appear likely that the Lone Gull deposit could be processed in a similar manner to the Rabbit Lake ore, unless the lower silicon and higher aluminum content, indicative of a higher clay content in the ore in this case, presents a processing problem. Hence, the likely tailings composition would be similar to that produced from the original Rabbit Lake mill.

The Blizzard deposit is unique in Canada, being a calcium/magnesium uranyl phosphate. It would require a novel method of processing to recover uranium from this ore, significantly different from any of the processes in current significantly different from any of the processes in current use. However, calcium phosphates are commonly leached with sulphuric acid to free the phosphate in fertilizer production and therefore, this initial sulphuric acid leach step (the same for all current Canadian uranium producers) may still be used. If so, sulphuric acid leach, uranium extraction, followed by neutralization may be applicable. Some of the process chemical contribution to the tailings, therefore, may not be significantly different from other acid leach uranium mills. In fact, the process chemicals which control the initial seepage chemistry, sulphuric acid and lime, would be the same.

The Kitts/Michelin deposit is different from other uranium ores in that, while the uranium is carried as pitchblende, it has a high calcite gangue content. Calcite, calcium carbonate, in any ore results in very high acid requirement in the leach process, as carbonates are acid-consuming. In the United States and at Beaverlodge in Saskatchewan, high carbonate ores have been processed by the alkali leach method. This method, while having lower overall uranium recoveries, is significantly less expensive because of the reduction in leach acid costs. Reagents used in this process, among them sodium carbonate, sodium bicarbonate, and sodium hydroxide to precipitate the leached uranium, would be expected to result in a different tailings composition from that resulting from an acid leach mill. For example, residue sulphate levels could be lower, although the pH value would still be of the order of pH 10. Table 12-5 gives a "typical" alkali leach tailings liquid chemistry. This is not particularly different from the acid levels tailings liquid in its sulphate content, but carbonate and bicarbonate are greatly increased. Actual composition will depend, however, on detailed ore chemistry and processing techniques.

12.4 Tailings Seepage Composition

From the evaluation in Sections 11.1 to 11.4 above, it is possible to suggest the following tailings seepage compositions, for the potential and possible uranium producing areas, by comparison with the compositions derived earlier in this study. It must be remembered that the actual ore composition and selected processing circuit could greatly affect these extrapolations.

potential producing areas:

- most of northern Saskatchewan, including Cigar Lake, Midwest Lake, Dawn Lake, McClean Lake, Collins Bay A and D-Zones will produce a "Key Lake" type of liquid with the proviso that the Cigar Lake tailings will probably carry higher radionuclide levels because of the higher grade ore;
- the Collins Bay Eagle Zone will probably produce a "Rabbit Lake" type of liquid, but possibly with a higher aluminum content from the clay type of ore, although aluminum sulphate solubility may still be the overall control on its concentration.

possible producing areas:

- Lone Gull, NWT will probably produce a "Rabbit Lake" type of liquid;

TABLE 12-5
CHEMICAL COMPOSITION OF A TYPICAL, UNITED STATES ALKALI LEACH TAILINGS

CO3	mg/L	7000
HC03	mg/L	100000
Se	mg/L	40
SO4	mg/L	7600
Cl	mg/L	700
Mo	mg/L	80
V205	mg/L	40
U308	mg/L	40
pH	mg/L	10-10.5
Ra226	pCi/L	200 (10*Bq/L)

NOTE: All units are mg/L unless otherwise indicated

(from United States Nuclear Regulatory Commission 1979)

- the type of liquid which would be produced at Blizzard, British Columbia is unknown, because of phosphate content; and
- the type of liquid which would be produced at Kitts/Michelin, Labrador is unknown, because of high calcite content, but could be similar to U.S. alkali-leach mill tailings, if such a process circuit is used.

In essence, with the exception of the Blizzard deposit in British Columbia and the Kitts/Michelin deposits in Labrador, the tailings seepage composition for the potential and possible uranium producing areas can be considered the same as the seepage compositions developed for current producing areas and, subsequently, the "generic", process controlled Stage 1 seepage chemistry. Thus the behavior of barrier materials projected for current areas is expected to apply to the future operations with the noted exceptions.

13.0 RECOMMENDATIONS FOR PHASE II STUDY

13.1 Deficiencies Identified in Phase I Program

Review of existing information has identified a lack of data in several areas. Further information is required on:

- The mineralogy of potential natural barrier materials;
- The effect of the position of the phreatic surface (i.e. saturated or unsaturated conditions) on the redox potential and hence the type of chemical reactions that can be anticipated;
- Chemical reactions with the groundwater that could affect the composition of the seepage and hence impact on barriers constructed of natural materials;
- Actual permeability of the natural materials;
- Changes in permeability with time;
- Changes in permeability with chemical reactions, particularly reactions forming precipitates and data quantifying the change.

13.2 Objectives of Phase II

The lack of numerical data in Phase I made it extremely difficult to predict contaminant transfer rates. The objective of the Phase II program is to generate reliable data that can be used as input to modelling the seepage pathway in a saturated flow model. The parameters required include horizontal and vertical permeability coefficients (K_h, K_v), porosity (n), bulk density (ρ_b), advective velocity (v), dispersion coefficients (D_α) and distribution coefficients (K_d).

13.3 Test Program

A constant head permeability device that accurately measures changes in vertical permeability and changes in sample volume would suffice. By direct measurement, permeability, bulk density, porosity, initial and final moisture contents can be measured. "K_d's" can be calculated knowing the volumes of influent solution, mass of material in the permeameter, effluent volume, initial and final chemistry. The longitudinal dispersivity can be estimated by plotting the variation in contaminant concentration for a chemical species with time, using established relationships. Seepage velocities can be obtained by calculation, knowing the gradients.

The compressibility relationship for the soils would be established by oedometer testing. In addition, moisture content-permeability relationships would be established by testing in Tempe cells.

Leachate Composition

Leachate would be prepared to conform to a selected tailings site. It is assumed the leachate would be stable in an aerobic environment. It is proposed that leachate be prepared to conform to composition for each of the four seepage stages, i.e. process controlled, sulphide oxidation, resolution and long-term stages. Thus, the samples would be tested utilizing four leachates.

Test Material

It is proposed to test typical till, peat, silt, and a bentonite modified till material from northern Saskatchewan.

Sequencing

It is proposed to establish permeability test columns and to put the tailings seepage through the columns in sequence, approximating the sequence of flow in nature. There would be only two sequences namely:

- Process controlled effluent followed by sulphide oxidation effluent, then re-solution, then long-term; and,
- Process control-re-solution-long-term.

This means that there would be two runs per material and each material would be tested in duplicate. Thus, there would be a total of 16 samples tested.

Soil Mineralogy and Chemistry

The mineralogy of each candidate material would be determined. In addition, whole sample chemical analyses would also be run before and after the tests.

Test Site Location

It is proposed to conduct the tests in the Saskatoon laboratory of the Saskatchewan Research Council. All pertinent regulations regarding handling and disposal of radioactive materials would be adhered to.

13.4 Schedule and Cost

It is anticipated that each test sequence would take approximately three months to complete. A total of seven months is required to adequately complete the testing.

The estimated cost of this work is $67,000.00.

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APPENDIX 'A'

APPENDIX A

CLUFF LAKE STUDY AREA DATA

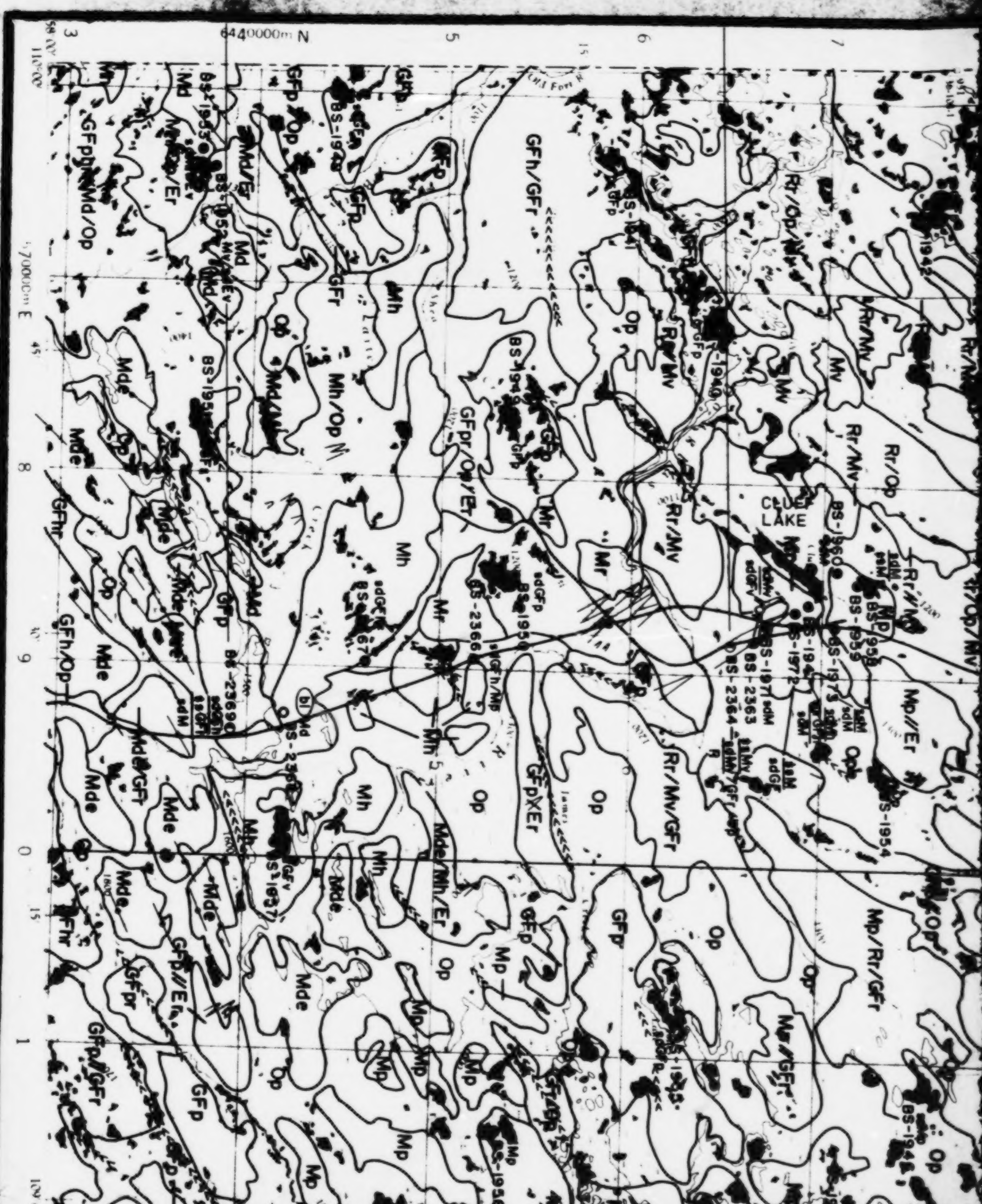
The Cluff Lake Study Area is shown on Figure A-1. This map shows the surficial geology and some glacial features. Figure A-2 defines symbols and geological units on the map.

Information on the Cluff Lake Study Area was obtained from the following publications. A full listing of the references is found in the References of this report.

- Saskatchewan Research Council, 1982
- W.A. Meneley Consultants Ltd., no date
- Stearns-Roger Canada Ltd., 1976
- Schreiner, B.T., 1984

A summary of data for this study area can be found in Table 5-2 of the main report.

Data on the following tables has been categorized according to the geologic unit or textural classification. For each collection of data, maximum minimum, average values and number of measurements made are tabulated.



6440000m N
470000m E
CLUFF LAKE
GFh/GFr
GFp/Op/Er
Rr/Op
Rr/Mv
Rr/Mv/GFr
Mp//Er
Mp/Rr/GFr
Mde/Mh/Er
Mh/Op
Mde
Mh
Mr
Mp
Op
GFp
GFpr
GFhr
GFh/Op
GFp//Er
GFp//GFr
GFp/GFr
Mde/GFr
GFpg/Md/Op
BS-1942
BS-1943
BS-1946
BS-1950
BS-1953
BS-1954
BS-1955
BS-1958
BS-1959
BS-1960
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BS-1973
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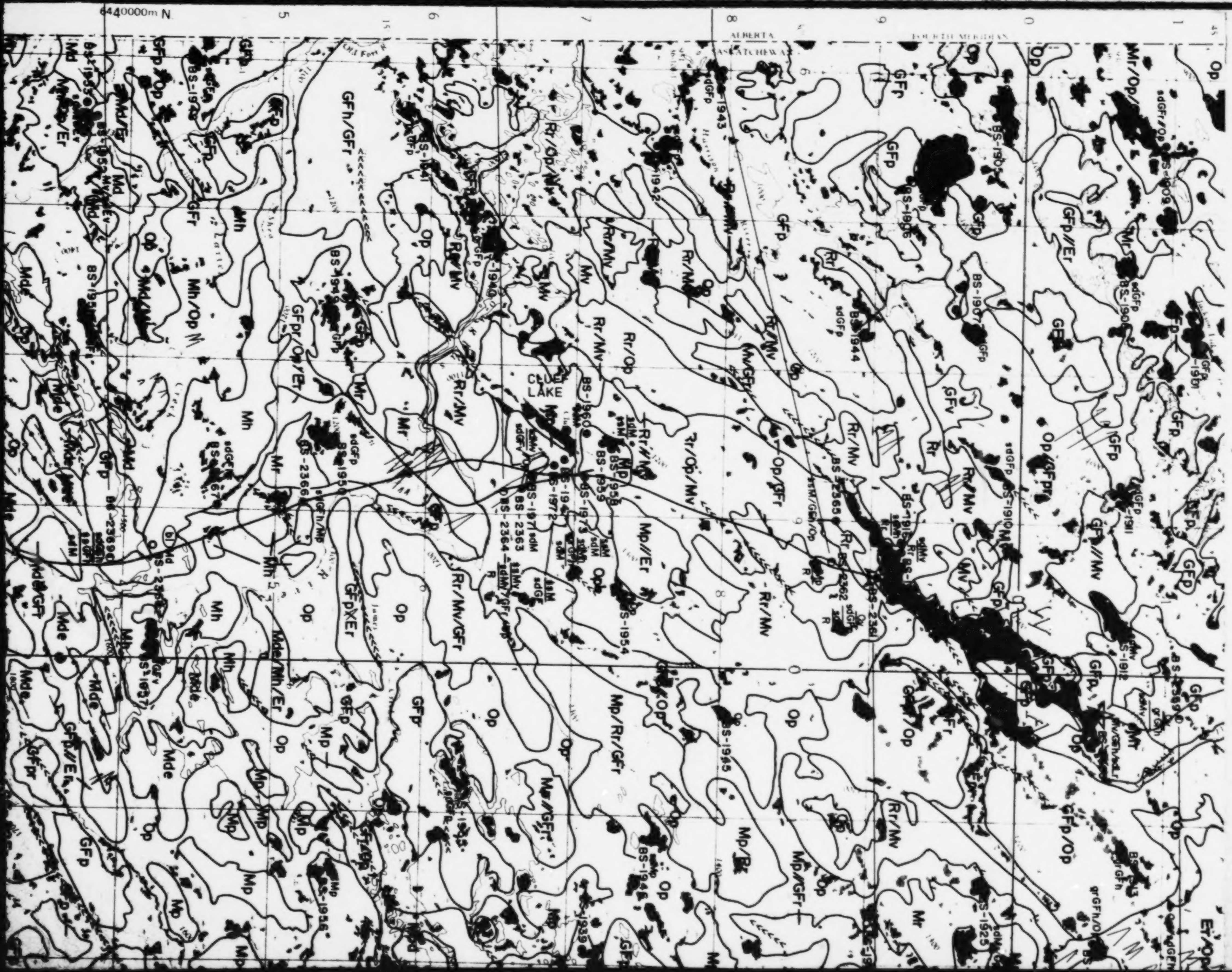
BS-2364
BS-2366
BS-2367
BS-2369



(AFTER B.T. SCHREINER, SASK ENERGY AND MINES OPEN FILE REPORT 84-17, 1984)

Clifton Associates Ltd.

CONSULTING GEOTECHNICAL ENGINEERS
REGINA SASKATOON

CLIENT

NATIONAL URANIUM TAILINGS PROGRAM

PROJECT

NATURAL MATERIALS AS BARRIERS FOR URANIUM MINE TAILINGS

TITLE

SURFICIAL GEOLOGY OF CLUFF LAKE AREA

DATE 85/12/06	APPD BY	FIGURE A-1	
SCALE AS NOTED	DWN BY J.M.B.		

LEGEND

Terrain Classification

GEOMORPHIC MODIFIER	ENVIRONMENT CATEGORIES						
	R ROCK	M MORAINAL	A ALLUVIAL	GF GLACIOFLUVIAL	GL GLACIO LACUSTRINE	O ORGANIC	E EOLIAN
c concealed	obscured only by vegetation	—	—	—	—	—	stabilized by vegetation
w weathered	frost-broken (felsenmeer)	winnowed "washed" and subdued by wave action				—	blowouts
e eroded	ice scoured	channelled by former streams of glacial meltwater in a braided or parallel pattern				—	—
g gullied	—	dissected by modern ravines in a dendritic pattern					
k collapsed	karst	kettled	—	kettled	kettled	—	—
p plain	plain	plain	floodplain	outwash plain	plain	bog	plain
v veneer	—	thin enough — usually less than 3 metres thick — to reveal geomorphic fabric of underlying formation					
r ridged	corrugated with parallel stratification ridges igneous and tectonic foliation	transverse elements, end, minor moraines	point bars	eskerine complex	beach berms strandlines and wave-cut benches	string bog	dunes
h hummocky	—	ablational and chaotic disintegration moraines	—	hummocky terrain kames, kettles	—	palsa	dunes
d drumlinoid	—	longitudinal elements drumlins, flutings crag and tail hills	—	—	—	—	—
t terrace	—	terrace bench	terrace bench	kame terrace	terrace bench	—	—

Example: Glaciolacustrine plain

GL p

Environment Category

Geomorphic Modifier

FIGURE A-2

TABLE A-1
CLUFF LAKE AMOK DATA, SAND

					GRADATION (% by weight)				GRAIN SIZE					
TEST HOLE	SAMPLE NUMBER	DEPTH (m)	THICKNESS (m)	SPT N	CLAY	SILT	SAND	GRAVEL	D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	COEF. OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
TZ21	6	3	6.6	18	0	5	95	0	0.1	0.15	0.22	0.3	2.2	270
TZ21	8	6.1	6.6	9	0	3	97	0	0.11	0.2	0.3	0.35	2.72	74
TZ22	6	3.7	4.1	20	0	8	92	0	0.09	0.15	0.21	0.35	2.33	7.2
TZ23	6	3	5.5	20	0	1	99	0	0.12	0.19	0.24	0.29	2	14
TZ23	7	4.6	5.5	10	0	9	91	0	0.08	0.17	0.3	0.35	3.75	35
TZ23	8	6.1	1.6	4	0	3	97	0	0.12	0.21	0.3	0.35	2.5	7.5
TZ24	7	4.6	7.1	10	0	3	97	0	0.11	0.17	0.22	0.3	2	56
TZ24	10	7.6	7.1	10	0	3	97	0	0.15	0.22	0.31	0.36	2.06	30
MAX		7.6	7.1	20	0	9	99	0	0.15	0.22	0.31	0.36	3.75	270
MIN		3	1.6	4	0	1	91	0	0.08	0.15	0.21	0.29	2	7.2
AVE		4.83	5.51	12	0	4.37	95.62	0	0.11	0.18	0.26	0.33	2.44	61.71
NUM		8	8	8	8	8	8	8	8	8	8	8	8	8

TABLE A-2
CLUFF LAKE AMOK DATA, SANDY SILT

TEST HOLE	SAMPLE NUMBER	DEPTH (m)	THICKNESS (m)	SPT N	GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	GRAIN SIZE D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	COEF. OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
TZ21	10	9.1	1.5	7	5	60	35	0	0.01	0.01	0.05	0.12	9.6	2.5
TZ24	11A	9.1		13	2	52	46	0	0.01	0.02	0.08	0.22	9.75	
MAX		9.1	1.5	13	5	60	46	0	0.01	0.02	0.08	0.22	9.75	2.5
MIN		9.1	1.5	7	2	52	35	0	0.01	0.01	0.05	0.12	9.6	2.5
AVE		9.1	1.5	10	3.5	56	40.5	0	0.01	0.02	0.06	0.17	9.675	2.5
NUM		2	1	2	2	2	2	2	2	2	2	2	2	1

TABLE A-3
CLUFF LAKE AMOK DATA, SILTY SAND

					GRADATION (% by weight)				GRAIN SIZE					
TEST HOLE	SAMPLE NUMBER	DEPTH (m)	THICKNESS (m)	SPT N	CLAY	SILT	SAND	GRAVEL	D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	COEF. OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
TZ24	5	1.8	1.6	13	0	28	72	0	0.03	0.08	0.15	0.25	5	66
TZ25	5	1.8	2.5	11	0	28	72	0	0.02	0.08	0.15	0.25	7.5	67
TZ23	9	7.6	1.6	4	0	22	78	0	0.03	0.08	0.15	0.25	5	3.6
TZ22	8A	6.1	0.3	17	0	36	59	5	0.01	0.5	0.15	0.35	15	8.7
TZ25	6	3	2.5	14	0	18	82	0	0.02	0.12	0.2	0.3	9.09	67
TZ27	1A	0	0.6	18	0	41	59	0	0.02	0.04	0.13	0.28	8.666	
MAX		7.6	2.5	18	0	41	82	5	0.03	0.5	0.2	0.35	15	67
MIN		0	0.3	4	0	18	59	0	0.01	0.04	0.13	0.25	5	3.6
AVE		3.38	1.51	12	0	28.8	70.33	0.83	0.02	0.15	0.15	0.28	8.376	42.46
NUM		6	6	6	6	6	6	6	6	6	6	6	6	5

TABLE A-4
CLUFF LAKE AMOK DATA, TILL

TEST HOLE	SAMPLE NUMBER	DEPTH (m)	THICKNESS (m)	SPT N	GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	GRAIN SIZE D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	COEF. OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
TZ20	3A	0.9	2.3	27	0	31	43	26	---	0.08	0.3	10		1.9
TZ20	4	1.8	2.3	28	0	22	60	18	----	0.12	0.35	11		1.9
TZ22	8B	6.7	2.2	17	0	3	76	21	0.12	0.18	0.28	12	2.33	8.7
TZ22	9	7.6	2.2	25	0	13	70	17	---	0.22	0.3	10		87
TZ26	3	2.4	3.4	54	0	10	65	25	0.01	0.27	0.72	12	90	1
TZ27	2	1.2	1.9	23	0	16	49	35	---	0.18	0.8	22		3600
TZ23	10A	9.1	2.7	31	0	14	65	21	0.08	0.18	0.3	10	3.75	
TZ26	1B	0.8	3.4	36	0	11	50	39	---	0.3	1.8	21		
TZ26	4	2.1	3.4	47	0	6	32	68	0.18	0.54	20	30	111.1	
TZ26	5	1.8	3.4	57	0	18	76	6	---	0.12	0.27	0.6		4
TZ27	3	0.9	1.9	63	0	11	38	51	0.08	0.28	5	15	66.66	3600
TZ27	4	2.1	1.9	100	0	15	74	11	---	0.17	0.37	1.2		
MAX		9.1	3.4	100	0	31	76	68	0.18	0.54	20	30	111.1	3600
MIN		0.8	1.9	17	0	3	32	6	0	0.08	0.27	0.6	2.33	1
AVE		3.11	2.58	42	0	14.2	58.16	28.16	0.04	0.22	2.54	12.9	54.77	913.06
NUM		12	12	12	12	12	12	12	12	12	12	12	5	8

TABLE A-5
SRC DATA, CLUFF LAKE COLLUVIUM

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION
232811	74K 6	1.0	1.0	1	17	82	0.26	C --
	MAX	1.0	1.0	1	17	82	0.26	
	MIN	1.0	1.0	1	17	82	0.26	
	AVE	1.0	1.0	1	17	82	0.26	
	NUM	1.0	1.0	1	1	1	1	

TABLE A-6
SRC DATA, CLUFF LAKE GRAVEL

SITE	NTS		DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
					CLAY	SILT	SAND			
233021	74K	6	0.8	1.8	0	5	95	0.4	E	--
233022	74K	6	1.1	1.8	0	5	95	0.22	E	--
233023	74K	6	1.5	1.8	0	2	98	0.49	E	--
233024	74K	6	2.0	1.8	0	1	99	0.5	E	--
233031	74K	6	2.5	1.1	0	1	99	0.57	E	--
233032	74K	6	3.0	1.1	0	0	100	0.62	E	--
233251	74K	6	2.0	0.8	0	2	98	0.48	E	--
233252	74K	6	2.3	0.8	0	0	100	0.49	E	--
191311	74K	11	0.6		2	2	96	0.47	GF	
236611	74K	3	1.0	1.2	0	1	99	0.82	GF	/
236621	74K	3	1.5	0.4	0	0	100	0.71	GF	/
236713	74K	3	0.9	1.0	0	0	100	0.89	GF	
194011	74K	5	0.8		0	0	100	0.66	GF	
194111	74K	5	0.5		3	4	93	0.78	GF	
194911	74K	4	0.5		0	7	93	0.68	GF	
232631	74K	5	1.3	0.2	0	5	95	0.32	GF	--
232911	74K	6	0.3	1.0	1	4	95	0.42	GF	--
232912	74K	6	0.5	1.0	1	3	96	0.46	GF	--
232913	74K	6	0.8	1.0	0	1	99	0.3	GF	--
234441	74K	5	2.2	1.5	1	3	96	0.55	M	--
234442	74K	5	2.5	1.5	1	2	97	0.45	M	--
234443	74K	5	3.0	1.5	1	2	97	0.72	M	--
234633	74K	6	2.9	1.1	3	6	91	0.28	M	--
194721	74K	5	2.0	1.0	0	0	100	0.2	M	--
233131	74K	6	1.8	1.1	5	5	90	0.24	M	--
233132	74K	6	2.2	1.1	2	3	95	0.38	M	--
233141	74K	6	2.8	2.4	0	1	99	0.42	M	--
233142	74K	6	3.2	2.4	0	1	99	0.6	M	--
233143	74K	6	3.5	2.4	0	1	99	0.64	M	--
233144	74K	6	4.0	2.4	0	0	100	0.85	M	--
235922	74K	11	3.0	2.7	0	1	99	0.51	O	--
236122	74K	11	3.0	7.0		4	96	0.31	O	--
236125	74K	11	7.6	7.0	2	2	96	0.71	O	--
	MAX		7.6	7.0	5	7	100	0.89		
	MIN		0.3	0.2	0	0	90	0.2		
	AVE		2.0	1.8	0.68	2.24	97.09	0.51		
	NUM		33.0	29.0	32	33	33	33		

TABLE A-7
SRC DATA, CLUFF LAKE PEAT

SITE	NTS		DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
					CLAY	SILT	SAND			
232812	74K	6	1.1	.					C	--
236021	74K	11	0.5	0.1					M	/
235910	74K	11	0.6	0.6					O	--
236111	74K	11	0.2	2.4					O	--
236112	74K	11	1.0	2.4					O	--
236113	74K	11	1.4	2.4					O	--
236115	74K	11	2.4	2.4					O	--
	MAX		2.4	2.4						
	MIN		0.2	0.0						
	AVE		1.0	1.5						
	NUM		7.0	7.0						

TABLE A-8
SRC DATA, CLUFF LAKE SAND

SITE	NTS		DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
					CLAY	SILT	SAND			
236911			0.8	14.4	0	1	99	0.26		
236912			2.1	14.4	5	19	76	0.1		
236913			4.6	14.4	1	7	92	0.11		
236914			7.6	14.4	1	16	83	0.09		
236915			12.2	14.4	2	25	73	0.4		
236916			14.0	14.4	4	44	52	0.09		
233311	74K	5	0.3	0.4	0	32	68	0.1	E	–
236631	74K	3	2.0	0.4	0	0	100	0.22	GF	/
236711	74K	3	0.4	1.0	4	22	74	0.43	GF	
236712	74K	3	0.6	1.0	0	0	100	0.65	GF	
190111	74K	12	0.7		0	1	99	0.37	GF	
190511	74K	12	0.9		1	0	99	0.2	GF	
190611	74K	12	0.9		1	0	99	0.21	GF	
190711	74K	12	0.4		3	5	92	0.44	GF	
190811	74K	12	0.6		0	19	81	0.09	GF	
191011	74K	12	0.8		0	0	100	0.4	GF	
191111	74K	11	0.7		0	0	100	0.21	GF	
191411	74K	11	0.9		1	2	97	0.39	GF	
194211	74K	5	0.8		0	0	100	0.44	GF	
194311	74K	5	1.0		0	0	100	0.4	GF	
194411	74K	12	0.9		0	1	99	0.42	GF	
194811	74K	4	0.9		0	0	100	0.36	GF	
195011	74K	4	1.0		0	0	100	0.47	GF	
195511	74K	6	0.9		0	0	100	0.3	GF	
190911	74K	12	1.0		1	7	92	0.29	GF	//
195111	74K	4	0.4		1	16	83	0.2	GF	
195711	74K	3	0.7		0	0	100	0.45	GF	
232611	74K	5	0.6	1.0	0	6	94	0.17	GF	–
197221	74K	5	0.8		2	2	96	0.17	M	–
234211	74K	5	0.1	0.2	5	18	77	0.19	M	–
234241	74K	5	2.0	0.5	3	5	92	0.19	M	–
234242	74K	5	2.2	0.5	3	12	85	0.3	M	–
234444	74K	5	3.3	1.5	1	1	98	0.49	M	–
195211	74K	4	0.5		0	8	92	0.42	M	/
232731	74K	5	1.3	0.2	0	8	92	0.26	M	–
236011	74K	11	0.2	0.5	0	0	100	0.35	M	/
236031	74K	11	0.8	0.5	0	0	100	0.27	M	/
236322	74K	6	1.5	0.8	0	0	100	0.54	M	–
235921	74K	11	1.4	2.7	2	7	91	0.4	O	–
236121	74K	11	2.5	7.0		4	96	0.21	O	–
236123	74K	11	4.0	7.0	3	21	76	0.09	O	–
236124	74K	11	6.0	7.0		1	99	0.3	O	–
236132	74K	11	13.8	5.0	5	14	81	0.2	O	–
	MAX		14.0	14.4	5	44	100	0.65		
	MIN		0.1	0.2	0	0	52	0.09		
	AVE		2.3	5.2	1.19	7.53	91.32	0.29		
	NUM		43.0	24.0	41	43	43	43		

TABLE A-9
SRC DATA, CLUFF LAKE SILT

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION
				CLAY	SILT	SAND		
233011	74K 6	0.3	0.6	5	54	41	0.14	E --
233211	74K 6	0.2	0.3	4	52	44	0.09	E --
233511	74K 5	0.2	0.4	4	63	33	0.08	E --
233711	74K 6	0.1	0.2	5	65	30	0.1	E --
	MAX	0.3	0.6	5	65	44	0.14	
	MIN	0.1	0.2	4	52	30	0.08	
	AVE	0.2	0.4	4.5	58.5	37	0.1	
	NUM	4.0	4.0	4	4	4	4	

TABLE A-10
SRC DATA, CLUFF LAKE UPPER TILL

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
				CLAY	SILT	SAND			
191611	74K 11	1.0		3	11	86	0.21	M	H
194611	74K 6	0.4		0	12	88	0.19	M	P
194711	74K 5	1.0	1.5	4	21	75	0.33	M	H
195911	74K 4	0.8	0.8	2	20	78	0.58	M	
196011	74K 4	1.0	1.2	2	14	84	0.31	M	
197113	74K 5	3.0		2	9	89	0.24	M	
197211	74K 5	1.0		9	20	71	0.22	M	
233111	74K 6	0.3	0.7	1	8	91	0.33	M	V
233112	74K 6	0.5	0.7	0	4	96	0.34	M	V
233221	74K 6	0.4	0.4	1	16	83	0.18	E	V
233222	74K 6	0.5	0.4	3	20	77	0.27	E	V
233231	74K 6	0.7	0.5	2	18	80	0.23	E	V
233232	74K 6	0.9	0.5	0	37	63	0.18	E	V
233241	74K 6	1.2	0.9	0	11	89	0.22	E	V
233242	74K 6	1.4	0.9	0	3	97	0.26	E	V
233243	74K 6	1.6	0.9	0	4	96	0.27	E	V
233321	74K 5	0.5	0.5	0	11	89	0.2	E	V
233322	74K 5	0.7	0.5	0	9	91	0.23	E	V
233331	74K 5	0.9	0.5		13	87	0.17	E	V
233332	74K 5	1.1	0.5	1	17	82	0.16	E	V
233341	74K 5	1.3	0.6	1	12	87	0.25	E	V
233342	74K 5	1.5	0.6	1	10	89	0.23	E	V
233343	74K 5	1.6	0.6	2	6	92	0.26	E	V
233411	74K 6	0.1	0.4	6	16	78	0.28	M	V
233412	74K 6	0.3	0.4	3	12	85	0.22	M	V
233421	74K 6	0.5	0.5	10	23	67	0.39	M	V
233422	74K 6	0.7	0.5	7	22	71	0.22	M	V
233521	74K 5	0.5	0.3	3	4	93	0.24	E	V
233531	74K 5	0.7	0.5	4	5	91	0.37	E	V
233532	74K 5	0.9	0.5	2	13	85	0.23	E	V
233541	74K 5	1.2	1.1	2	8	90	0.32	E	V
233542	74K 5	1.5	1.1	1	2	97	0.34	E	V
233543	74K 5	1.8	1.1	3	4	93	0.28	E	V
233611	74K 6	0.2	0.5	1	14	85	0.25	M	
233612	74K 6	0.4	0.5	3	13	84	0.24	M	
233721	74K 6	0.3	0.4	2	14	84	0.19	E	V
233731	74K 6	0.7	0.9	3	14	83	0.28	E	V
233732	74K 6	1.0	0.9	1	11	88	0.19	E	V
233733	74K 6	1.2	0.9	3	4	93	0.21	E	V
233811	74K 6	0.2	0.4	0	17	83	0.25	M	

TABLE A-10
SRC DATA, CLUFF LAKE UPPER TILL (cont'd.)

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
233812	74K 6	0.3	0.4	1	19	80	0.22	M	
233821	74K 6	0.5	0.7	0	11	89	0.25	M	
233822	74K 6	0.8	0.7	0	12	88	0.26	M	
233911	74K 6	0.2	0.4	5	12	83	0.19	M	V
233912	74K 6	0.3	0.4	3	9	88	0.2	M	V
233921	74K 6	0.5	0.4	2	21	77	0.41	M	V
233922	74K 6	0.6	0.4	2	14	84	0.34	M	V
233941	74K 6	2.0	.	4	9	87	0.6	M	V
233942	74K 6	2.5	.	4	9	87	0.56	M	V
234011	74K 6	0.2	0.5	2	5	93	0.27	M	V
234012	74K 6	0.4	0.5	4	4	92	0.33	M	V
234021	74K 6	0.6	0.5	3	8	89	0.38	M	V
234022	74K 6	0.8	0.5	4	17	79	0.35	M	V
234031	74K 6	1.0	0.4	3	9	88	0.4	M	V
234032	74K 6	1.1	0.4	4	9	87	0.38	M	V
234041	74K 6	1.4	0.7	5	17	78	0.43	M	V
234042	74K 6	1.6	0.7	10	19	71	0.37	M	V
234051	74K 6	2.0	1.2	8	20	72	0.3	M	V
234052	74K 6	2.3	1.2	9	21	70	0.27	M	V
234053	74K 6	2.6	1.2	8	19	73	0.35	M	V
234054	74K 6	2.8	1.2	9	21	70	0.27	M	V
234111	74K 6	0.1	0.2	4	20	76	0.29	M	
234212	74K 5	0.6	0.8	5	15	80	0.22	M	
234221	74K 5	1.0	0.8	3	14	83	0.27	M	
234222	74K 5	1.2	0.8	6	13	81	0.28	M	
234231	74K 5	1.6	0.4	6	19	75	0.14	M	
234232	74K 5	1.7	0.4	3	9	88	0.3	M	
234251	74K 5	2.4	0.9	3	7	90	0.23	M	
234252	74K 5	2.7	0.9	3	11	86	0.21	M	
234253	74K 5	2.9	0.9	2	6	92	0.28	M	
234311	74K 6	0.2	0.8	7	19	74	0.31	M	
234312	74K 6	0.3	0.4	3	15	82	0.36	M	
234321	74K 6	0.6	0.6	3	14	83	0.31	M	
234322	74K 6	0.8	0.6	8	13	79	0.3	M	
234411	74K 5	0.2	0.4	2	13	85	0.23	M	
234422	74K 5	0.7	1.0					M	
234521	74K 6	0.6	0.6	4	4	92	0.23	M	
234522	74K 6	0.9	0.6	3	4	93	0.29	M	
234531	74K 6	1.1	1.1	0	4	96	0.44	M	
234532	74K 6	1.3	1.1	1	9	90	0.26	M	

TABLE A-10
SRC DATA, CLUFF LAKE UPPER TILL (cont'd.)

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
234533	74K 6	1.5	1.1	3	9	88	0.35	M	
234534	74K 6	1.7	1.1	2	12	86	0.23	M	
234535	74K 6	1.9	1.1					M	
234611	74K 6	0.4	0.9	1	17	82	0.2	M	
234612	74K 6	0.7	0.9	3	10	87	0.35	M	
234711	74K 5	0.2	0.4	2	28	70	0.17	M	
234712	74K 5	0.3	0.4	3	11	86	0.19	M	
234721	74K 5	0.5	0.7	7	16	77	0.33	M	
234722	74K 5	0.7	0.7	8	15	77	0.3	M	
234723	74K 5	0.9	0.7	7	19	74	0.27	M	
234731	74K 5	1.1	.	8	15	77	0.29	M	
234732	74K 5	1.5	.	8	22	70	0.22	M	
234811	74K 5	0.2	0.5	3	25	72	0.25	M	V
234812	74K 5	0.4	0.5	17	6	77	0.34	M	V
234821	74K 5	0.6	0.5	7	23	70	0.39	M	V
234822	74K 5	0.8	0.5	7	17	76	0.33	M	V
234911	74K 5	0.2	0.3	10	17	73	0.26	M	V
234921	74K 5	0.4	0.5	12	17	71	0.28	M	V
234922	74K 5	0.6	0.5	6	16	78	0.41	M	V
235011	74K 5	0.2	0.5	5	38	57	0.15	M	V
235012	74K 5	0.4	0.5	0	0	100	0.36	M	V
235021	74K 5	0.6	0.5	4	15	81	0.17	M	V
235022	74K 5	0.8	0.5	6	17	77	0.22	M	V
236411	74K 6	0.5	0.6	6	30	64	0.24	M	V
236521	74K 11	1.0	0.8	8	20	72	0.23	M	
236522	74K 11	1.2	0.8	10	20	70	0.26	M	
236523	74K 11	1.6	0.8	7	26	67	0.18	M	
236531	74K 11	1.8	0.4	6	21	73	0.21	M	
236810	74K 3	.	.					M	D
194731	74K 5	2.5	1.0	2	11	87	0.41	M	H
195812	74K 5	2.0		10	19	71	0.29	M	
195912	74K 4	1.0		4	33	63	0.38	M	
195913	74K 4	1.0		20	29	51	0.3	M	
196012	74K 4	2.2		6	18	76	0.32	M	
232621	74K 5	1.1	0.3	1	15	84	0.42	GF	V
232641	74K 5	1.8	.	1	21	78	0.14	GF	V
232921	74K 6	1.2	0.7	2	9	89	0.23	GF	V
232922	74K 6	1.4	0.7	1	8	91	0.28	GF	V
232923	74K 6	1.6	0.7	3	10	87	0.28	GF	V
234121	74K 6	0.3	0.5	3	17	80	0.28	M	

TABLE A-10
SRC DATA, CLUFF LAKE UPPER TILL (cont'd.)

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
				CLAY	SILT	SAND			
234122	74K 6	0.5	0.5	4	18	78	0.31	M	
234151	74K 6	2.2		0	7	93	0.42	M	
234421	74K 5	0.5	1.0	4	17	79	0.37	M	
234423	74K 5	0.9	1.0	11	20	69	0.31	M	
234621	74K 6	1.2	1.2	4	11	85	0.23	M	
234622	74K 6	1.7	1.2	2	7	91	0.21	M	
235931	74K 11	3.4	1.5	2	2	96	0.41	O	V
235932	74K 11	4.6	1.5	2	3	95	0.33	O	V
236211	74K 6	1.5	3.0	2	3	95	0.55	M	P
191211	74K 11	0.6		1	12	87	0.25	M	V
195811	74K 5	1.2		1	12	87	0.3	M	
197111	74K 5	1.0	1.2	0	14	86	0.19	M	
197311	74K 5	1.0		8	25	67	0.23	M	
232711	74K 5	0.5	0.6	1	21	78	0.29	M	V
233121	74K 6	1.0	0.9	3	4	93	0.32	M	V
233122	74K 6	1.3	0.9	3	10	87	0.26	M	V
233431	74K 6	1.0	1.0	3	9	88	0.23	M	V
233432	74K 6	1.3	1.0	1	10	89	0.23	M	V
233433	74K 6	1.5	1.0	5	7	88	0.22	M	V
233621	74K 6	0.6	0.6	1	14	85	0.24	M	
233622	74K 6	0.8	0.6	2	11	87	0.19	M	
233631	74K 6	1.2	1.0	1	10	89	0.21	M	
233632	74K 6	1.5	1.0	2	10	88	0.24	M	
233633	74K 6	1.7	1.0	3	9	88	0.29	M	
234131	74K 6	0.8	0.6	3	8	89	0.33	M	
234132	74K 6	1.0	0.6	1	8	91	0.49	M	
234331	74K 6	1.1	1.0	2	8	90	0.2	M	
234332	74K 6	1.4	1.0	3	10	87	0.23	M	
234333	74K 6	1.7	1.0	3	6	91	0.21	M	
234511	74K 6	0.2	0.5	3	44	53	0.2	M	
234512	74K 6	0.4	0.5	3	16	81	0.22	M	
236311	74K 6	0.4	0.8	5	16	79	0.27	M	V
236312	74K 6	0.7	0.8	2	15	83	0.21	M	V
	MAX	4.6	3.0	20	44	100	0.6		
	MIN	0.0	0.0	0	0	51	0.14		
	AVE	1.0	0.7	3.71	13.76	82.54	0.28		
	NUM	153.0	142.0	149	150	150	150		

TABLE A-11
SRC DATA, CLUFF LAKE MIDDLE TILL

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
				CLAY	SILT	SAND			
195611	74K 3	0.6		6	15	79	0.42	M	P
197112	74K 5	2.0	2.5	5	12	83	0.2	M	
232721	74K 5	0.8	0.7	1	15	84	0.39	M	V
232931	74K 6	1.6	0.6	12	9	79	0.23	GF	V
232932	74K 6	1.8	0.6	8	9	83	0.26	GF	V
233041	74K 6	3.5	.	1	11	88	0.3	E	V
233151	74K 6	5.2	.	2	3	95	0.37	M	V
233261	74K 6	2.7	0.9	0	9	91	0.24	E	V
233262	74K 6	3.0	0.9	1	6	93	0.2	E	V
233263	74K 6	3.2	0.9	7	13	80	0.25	E	V
233354	74K 5	3.5	1.4	1	6	93	0.19	E	V
233441	74K 6	2.0	3.4	3	10	87	0.23	M	V
233442	74K 6	2.5	3.4	1	10	89	0.2	M	V
233551	74K 5	2.2	.	2	8	90	0.25	E	V
233552	74K 5	2.5	.	3	5	92	0.27	E	V
233553	74K 5	3.0	.	1	8	91	0.26	E	V
233641	74K 6	2.2	1.2	6	10	84	0.24	M	
233642	74K 6	2.4	1.2	6	10	84	0.22	M	
233643	74K 6	0.6	1.2	7	6	87	0.23	M	
233651	74K 6	3.2	.	3	8	89	0.23	M	
233751	74K 6	2.5	.	10	9	81	0.26	E	V
234141	74K 6	1.5	1.0	9	12	79	0.24	M	
234142	74K 6	1.5	1.0	3	12	85	0.22	M	
234143	74K 6	1.8	1.0	2	12	86	0.26	M	
234261	74K 5	3.2	0.4	3	12	85	0.46	M	
234341	74K 6	2.0	.	1	7	92	0.2	M	
234342	74K 6	2.5	.	0	7	93	0.26	M	
234343	74K 6	3.0	.	2	6	92	0.21	M	
234344	74K 6	3.5	.	1	5	94	0.28	M	
234431	74K 5	1.1	1.0	9	16	75	0.42	M	
234432	74K 5	1.4	1.0	9	19	72	0.33	M	
234433	74K 5	1.7	1.0	9	18	73	0.32	M	
234434	74K 5	1.9	1.0	10	20	70	0.32	M	
234541	74K 6	2.2	.	1	8	91	0.22	M	
234542	74K 6	2.4	.	4	12	84	0.26	M	
234631	74K 6	2.2	1.1	0	6	94	0.21	M	
234632	74K 6	2.6	1.1	1	9	90	0.2	M	
236126	74K 11	9.2	7.0	1	1	98	0.45	O	V
236131	74K 11	12.2	5.0	2	3	95	0.28	O	V
236321	74K 6	1.0	0.8	5	4	91	0.19	M	V

TABLE A-11
SRC DATA, CLUFF LAKE MIDDLE TILL (cont'd.)

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
236422	74K 6	1.2	0.9	3	3	94	0.32	M	V
192511	74K 11	0.5		0	13	87	0.35	M	R
195311	74K 4	0.6		1	2	97	0.42	M	R
233351	74K 5	1.9	1.4	2	10	88	0.23	E	V
233352	74K 5	2.2	1.4	10	9	81	0.22	E	V
233353	74K 5	2.5	1.4	1	6	93	0.23	E	V
233741	74K 6	1.5	1.2	3	11	86	0.24	E	V
233742	74K 6	1.9	1.2	3	9	88	0.43	E	V
233743	74K 6	2.2	1.2	2	11	87	0.2	E	V
233831	74K 6	1.2	1.4	0	9	91	0.27	M	
233832	74K 6	1.5	1.4	0	10	90	0.2	M	
233833	74K 6	1.8	1.4	0	9	91	0.23	M	
233834	74K 6	2.1	1.4	2	5	93	0.2	M	
233841	74K 6	2.4	0.5	1	7	92	0.16	M	
236421	74K 6	0.8	0.9	2	11	87	0.36	M	V
236511	74K 11	0.5	0.8	5	22	73	0.25	M	
	MAX	12.2	7.0	12	22	98	0.46		
	MIN	0.5	0.0	0	1	70	0.16		
	AVE	2.4	1.1	3.44	9.42	87.12	0.26		
	NUM	56.0	53.0	56	56	56	56		

TABLE A-12
SRC DATA, CLUFF LAKE LOWER TILL

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
232741	74K 5	1.8	.	1	15	84	0.33	M	V
232821	74K 6	1.4	.	6	41	53	0.21	C	V
234223	74K 5	1.4	0.8	8	16	76	0.23	M	
234451	74K 5	3.7	1.0	4	18	78	0.67	M	
234452	74K 5	4.0	1.0	4	15	81	0.41	M	
234453	74K 5	4.2	1.0	4	34	62	0.2	M	
234831	74K 5	1.0	.	20	19	61	0.34	M	V
234832	74K 5	1.2	.	10	20	70	0.29	M	V
234833	74K 5	1.5	.	7	21	72	0.27	M	V
234834	74K 5	2.0	.	7	19	74	0.33	M	V
234835	74K 5	2.5	.	10	18	72	0.24	M	V
234931	74K 5	0.8	.	8	22	70	0.28	M	V
234932	74K 5	1.0	.	10	20	70	0.25	M	V
234933	74K 5	1.5	.	7	21	72	0.22	M	V
234934	74K 5	2.0	.	6	23	71	0.24	M	V
234935	74K 5	3.0	.	2	14	84	0.33	M	V
234936	74K 5	4.5	.	9	21	70	0.21	M	V
235031	74K 5	1.0	.	6	17	77	0.28	M	V
235032	74K 5	1.2	.	9	17	74	0.27	M	V
235033	74K 5	1.5	.	6	17	77	0.23	M	V
235034	74K 5	2.0	.	9	20	71	0.26	M	V
235035	74K 5	3.0	.	7	18	75	0.37	M	V
234063	74K 6	3.6	1.1	6	18	76	0.61	M	V
236512	74K 11	0.8	0.8	6	18	76	0.29	M	
191511	74K 11	0.3	0.3	0	0	100	0.16	M	V
197312	74K 5	1.0		2	4	94	0.33	M	
233851	74K 6	2.8	.	12	14	74	0.22	M	
233852	74K 6	3.2	.	11	12	77	0.21	M	
233853	74K 6	3.5	.	15	13	72	0.22	M	
233854	74K 6	4.0	.	17	13	70	0.22	M	
233855	74K 6	5.5	.	16	15	69	0.21	M	
233931	74K 6	0.8	1.2	4	23	73	0.48	M	V
233932	74K 6	1.0	1.2	8	16	76	0.43	M	V
233933	74K 6	1.2	1.2	6	17	77	0.47	M	V
233934	74K 6	1.5	1.2	9	25	66	0.42	M	V
233935	74K 6	1.7	1.2	17	23	60	0.49	M	V
234061	74K 6	3.1	1.1	8	17	75	0.33	M	V
234062	74K 6	3.3	1.1	9	15	76	0.38	M	V
234641	74K 6	3.2	.	2	5	93	0.19	M	
234642	74K 6	3.6	.	2	16	82	0.2	M	

TABLE A-12
SRC DATA, CLUFF LAKE LOWER TILL (cont'd.)

SITE	NTS		DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
234643	74K	6	4.0	.	16	16	68	0.2	M	
234644	74K	6	4.5	.	16	15	69	0.2	M	
234645	74K	6	5.0	.	16	13	71	0.22	M	
234646	74K	6	5.8	.	25	19	56	0.2	M	
236141	74K	11	15.2	5.0	10	14	76	0.21	O	V
	MAX		15.2	5.0	25	41	100	0.67		
	MIN		0.3	0.0	0	0	53	0.16		
	AVE		2.8	0.4	8.73	17.48	73.77	0.29		
	NUM		45.0	44.0	45	45	45	45		

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APPENDIX 'B'

APPENDIX B

KEY LAKE STUDY AREA DATA

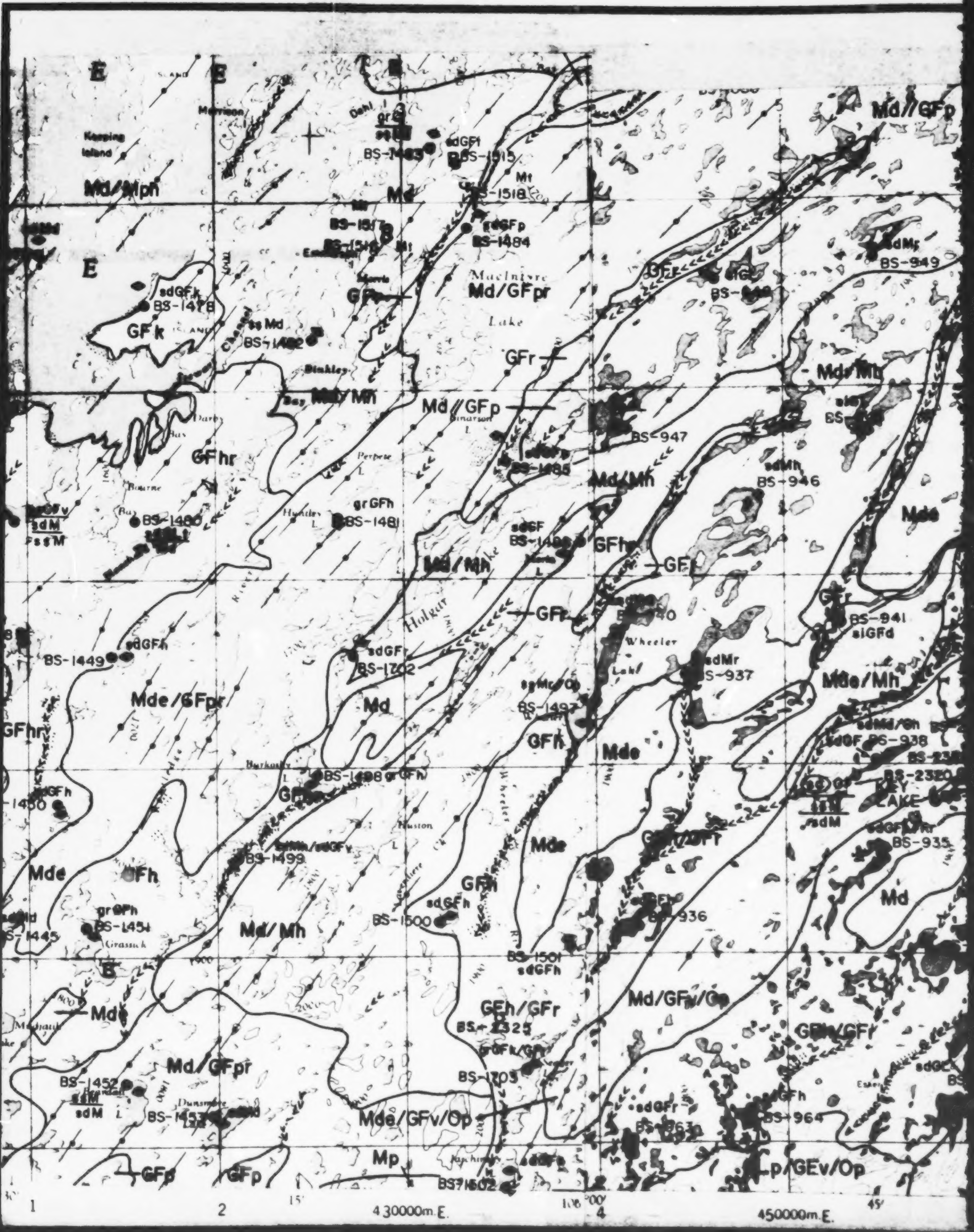
The Key Lake Study Area is shown on Figure B-1. This map shows the surficial geology and some glacial features. Figure B-2 defines symbols and geological units on the map.

Information on the Key Lake Study Area was obtained from the following publications. A full listing of the references is found in the References of this report.

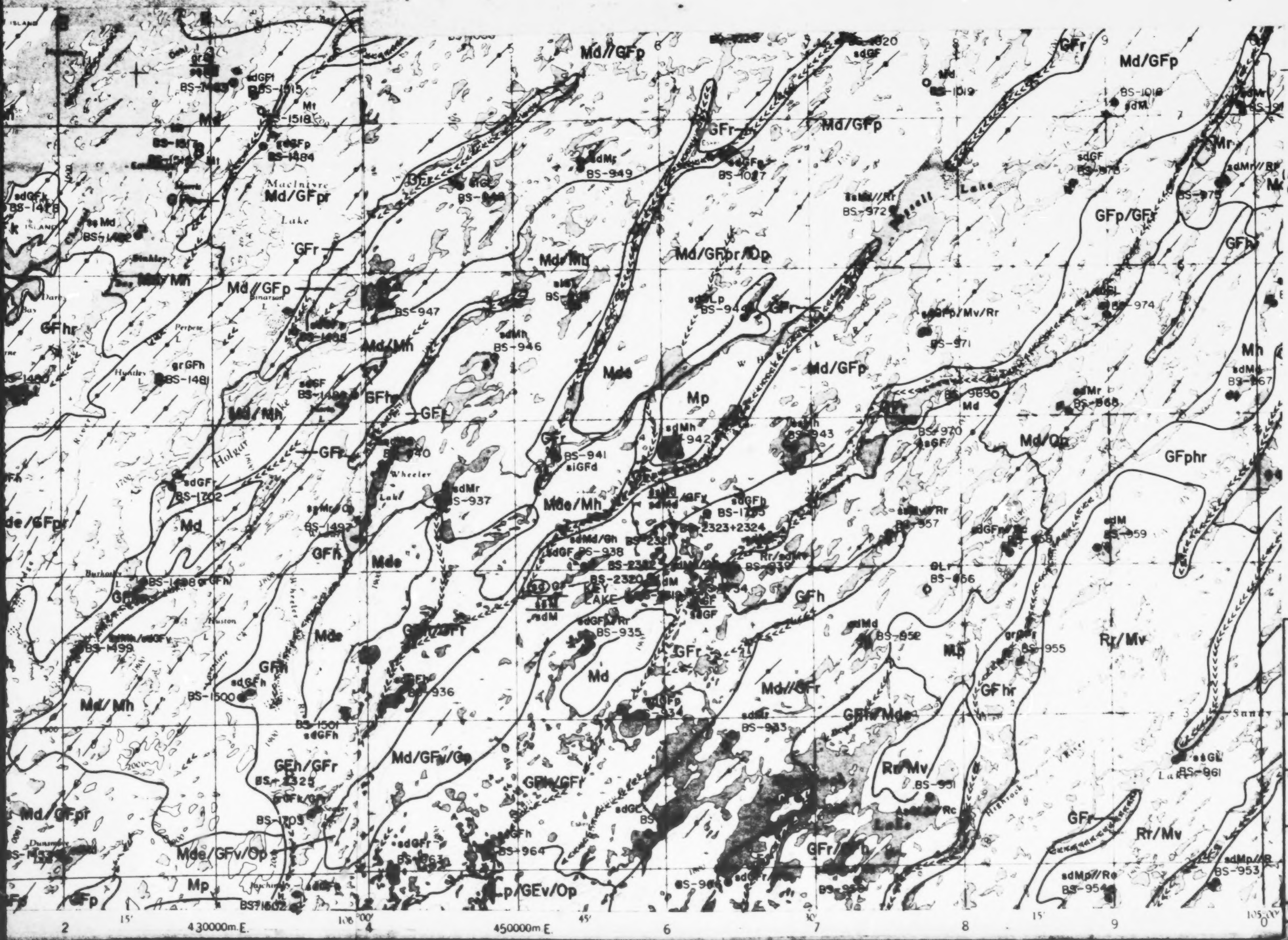
- Bayrock, L.A., 1977
- Stevenson International Groundwater Consultants Ltd., 1978
- Golder Associates, 1977a
- Golder Associates, 1977b
- Ground Engineering Ltd., 1978a
- Ground Engineering Ltd., 1978b
- Ground Engineering Ltd., 1978c
- Ground Engineering Ltd., 1978d
- Knight and Piesold Ltd., 1981
- Key Lake Mining Corporation, 1982
- Clifton Associates Ltd., 1978
- Schreiner, B.T., 1984

A summary of data for this study area can be found in Table 6-2 of the main report.

Data on the following tables has been categorized according to the geologic unit or textural classification. For each collection of data, maximum minimum, average values and number of measurements made are tabulated.



Md//GFp
Md/Mph
Kopping Island
Morrison
BS-1483
sdGFt
BS-1515
Mt
BS-1518
Md
BS-1517
BS-1516
sdGFp
BS-1484
sdGFk
BS-1478
GFk
ss Md
BS-1482
MacIntyre
Md/GFpr
Lake
GFp
GFr
Binkley Bay
Md/Mh
Md//GFp
Darby Bay
Einarson L
GFhr
Bourne Bay
BS-1480
BS-1485
BS-947
Md/Mh
BS-949
BS-946
sdMh
grGFh
BS-1481
Hunter L
sdGF
BS-1486
GFhr
Mde
Md/Mh
Holgar
GFr
BS-1440
Wheeler Lake
sdMr
BS-937
BS-941
siGFd
Mde/Mh
BS-1449
sdGFh
sdGFr
BS-1702
Mde/GFpr
Md
sgMr/Op
BS-1497
GFh
Mde
GFhr
BS-938
sdGF
sdMd/Gh
BS-2320
BS-1498
grGFh
Burkosky L
BS-1450
sdGFh
Huston L
sdGFh/sdGFv
BS-1499
Mde
Mde
GFh/GFr
sdGFh/Mr
BS-935
Md
BS-936
grGFh
BS-1451
Grassick
BS-1445
sdGFh
BS-1500
Md/Mh
GFh
BS-1501
sdGFh
Mde
GFh/GFr
BS-2325
Md/GFv/Op
GFh/GFr
grGFk/GFr
BS-1703
Md/GFpr
BS-1452
sdM
BS-1453
Dunsmore Lake
Mde/GFv/Op
sdGFr
BS-963
GFh
BS-964
Mp
GFp
GFp
BS-1502
sdGFp
Lp/GEv/Op
1
2
15'
430000m.E.
108°00'
4
450000m.E.
45'



(AFTER B.T. SCHREINER, SASK ENERGY & MINES OPEN FILE REPORT 84-11, 1984)

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KILOMETRES

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CLIENT
NATIONAL URANIUM TAILINGS PROGRAM

PROJECT
NATURAL MATERIALS AS BARRIERS FOR URANIUM MINE TAILINGS

TITLE
SURFICIAL GEOLOGY OF KEY LAKE AREA

DATE 85/12/06	APPD BY	FIGURE B-1	
SCALE AS NOTED	DWN BY J.M.B.		

LEGEND

Terrain Classification

GEOMORPHIC MODIFIER	ENVIRONMENT CATEGORIES						
	R ROCK	M MORAINAL	A ALLUVIAL	GF GLACIOFLUVIAL	GL GLACIO LACUSTRINE	O ORGANIC	E EOLIAN
c concealed	obscured only by vegetation	——	——	——	——	——	stabilized by vegetation
w weathered	frost-broken (felsenmeer)	winnowed "washed" and subdued by wave action				——	blowouts
e eroded	ice scoured	channelled by former streams of glacial meltwater, in a braided or parallel pattern				——	——
g gullied	——	dissected by modern ravines in a dentritic pattern					
k collapsed	karst	kettled	——	kettled	kettled	——	——
p plain	plain	plain	floodplain	outwash plain	plain	bog	plain
v veneer	——	thin enough — usually less than 3 metres thick — to reveal geomorphic fabric of underlying formation					
r ridged	corrugated with parallel stratification ridges igneous and tectonic foliation	transverse elements end minor moraines	point bars	eskerine complex	beach berms strandlines and wave-cut benches	string bog	dunes
h hummocky	——	ablational and chaotic disintegration moraines	——	hummocky terrain kames, kettles	——	palsa	dunes
d drumlinoid	——	longitudinal elements drumlins, flutings, crag and tail hills	——	——	——	——	——
t terrace	——	terrace bench	terrace bench	kame terrace	terrace bench	——	——

Example: Glaciolacustrine plain

GL p

Environment Category

Geomorphic Modifier

FIGURE B-2

TABLE B-1
GROUND ENGINEERING LTD. DATA, KEY LAKE PEAT

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	SPECIFIC GRAVITY	COMPRESSION INDEX	COEF. SECONDARY COMPRESSION	WATER CONTENT (%)	PERMEABILITY (m/s X 10+5)
MP-3	B588	0.0	4.3	1.67	3.8	0.02	652	
MP-1	B595	0.0	4.4		6.6	0.02	911	0.001
MP-3	B589	0.0	4.3		6.8	0.02	600	0.001
MP-3	B580	0.0	4.3		5.4	0.02	860	
MAX		0.0	4.4	1.67	6.8	0.02		0.001
MIN		0.0	4.3	1.67	3.8	0.02		0.001
AVE		0.0	4.3	1.67	5.65	0.02		0.001
NUM		4	4	1	4	4	4	2

TABLE B-2
GROUND ENGINEERING LTD. DATA, KEY LAKE CLAY

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			GRAIN SIZE				COEFFICIENT OF UNIFORMITY	WATER CONTENT (%)	PERMEABILITY (X10+5 m/s)
				SILT	SAND	GRAVEL	D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)			
TP12	B582	15.2	2.2	53	39	8	--	--	0.23	2			
MAX		15.2	2.2	53	39	8	0	0	0.23	2	0.0	0	0
MIN		15.2	2.2	53	39	8	0	0	0.23	2			
AVE		15.2	2.2	53	39	8	0	0	0.23	2	1.0	1	1
NUM		1	1	1	1	1	1	1	1	1	0.0	0	0

TABLE B-3
GROUND ENGINEERING LTD. DATA, KEY LAKE SAND

TEST HOLE	SAMPLE	DEPTH	THICKNESS	GRADATION (% by weight)			GRAIN SIZE				COEFFICIENT	WATER	
		(m)	(m)	SILT	SAND	GRAVEL	D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	OF UNIFORMITY	CONTENT (%)	PERMEABILITY (X10+5 m/s)
TM1	D165			22	78	0	--	0.11	0.22	0.58			
TM10	D142			5	70	25	0.13	0.22	0.7	22	5.4		
TM12	D154			24	76	0	--	0.12	0.23	0.57			
TM13	D95			22	78	0	--	0.09	0.2	0.3			
TM14	D164			20	79	1	--	0.09	0.16	0.28			
TM15	D166			16	84	0	--	0.12	0.21	0.27			
TM16	D175			8	92	0	0.094	0.19	0.24	0.29	2.6		
TM17	D174			5	95	0	0.12	0.21	0.3	0.78	2.5		
TM18	D167			23	77	0	--	0.083	0.17	0.27			
TM19	D163			18	82	0	--	0.12	0.22	0.55			
TM20	D93			7	93	0	0.09	0.18	0.26	0.7	3.1		
TM21	D103			38	62	0	--	--	0.11	0.23			
TM22	D121			34	58	8	--	--	0.17	0.3			
TM24	D125			13	87	0	--	0.16	0.28	0.78			
TM25	D146			5	94	1	0.1	0.2	0.3	0.66	3.0		
TM25	D152			12	88	0	--	0.18	0.27	0.68			
TM25A	D150			11	89	0	--	0.18	0.27	0.6			
TM26A	D148			12	88	0	--	0.17	0.26	0.65			
TM27	D140			7	57	36	0.12	0.3	1.5	15	12.5		
TM28	D135			18	82	0	--	0.1	0.2	0.29			
TM28	D170			4	94	2	0.13	0.21	0.39	1.1	3.0		
TM29	D127			18	81	1	--	0.1	0.21	0.6			
TM3	D97			15	85	0	--	0.11	0.21	0.3			
TM30	D119			27	73	0	--	0.076	0.15	0.3			
TM31	D105			33	67	0	--	--	0.2	0.29			
TM32	D92			3	97	0	0.17	0.21	0.29	0.7	1.7		
TM34	D168			34	66	0	--	--	0.21	0.32			
TM35	D173			2	98	0	0.17	0.22	0.35	0.75	2.1		
TM37	D172			2	98	0	0.18	0.22	0.35	0.75	1.9		
TM39	D107			20	80	0	--	0.1	0.21	0.3			
TM4	D99			31	69	0	--	--	0.18	0.3			
TM40	D117			23	77	0	--	0.08	0.13	0.24			
TM41	D137			16	84	0	--	0.11	0.22	0.55			
TM42	D139			21	79	0	--	0.11	0.24	0.64			
TM44	D115			10	90	0	0.08	0.18	0.28	0.83	3.5		
TM45	D109			35	65	0	--	--	0.11	0.27			
TM46	D88			7	93	0	0.13	0.2	0.29	0.65	2.2		
TM47	D89			10	90	0	0.075	0.18	0.26	0.65	3.5		
TM48	D111			13	87	0	--	0.13	0.24	0.3			
TM49	D113			14	86	0	--	0.13	0.23	0.29			

TABLE B-3
GROUND ENGINEERING LTD. DATA, KEY LAKE SAND (cont'd.)

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			GRAIN SIZE				COEFFICIENT OF UNIFORMITY	WATER CONTENT (%)	PERMEABILITY (X10+5 m/s)
				SILT	SAND	GRAVEL	D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)			
TM50	D131			42	58	0	--	--	0.18	0.3			
TP11	B561	0.2	5.3	1	99	0	0.19	0.21	0.4	0.5	2.1		
TP11	B562	0.2	5.3	6	94	0	0.18	0.21	0.45	0.65	2.5		
TP11	B563	0.2	5.3	4	67	29	8.6	1.5	6.5	12	0.8		
TP11	B564	0.2	5.3	2	86	12	0.19	0.4	0.75	3.5	3.9		
TP11	B568	10.7	1.2	2	98	0	0.18	0.21	0.3	0.8	1.7		
TP11C	B571	0	6	12	88	0	--	0.18	0.24	0.3			
TP11C	B572	0	6	1	99	0	0.18	0.2	0.24	0.29	1.3		
TP11C	B573	0	6	2	98	0	0.19	0.21	0.3	0.68	1.6		
TP11C	B574	0	6	2	98	0	0.18	0.2	0.28	0.6	1.6		
TP12	B577	0.2	0.7	5	95	0	0.12	0.2	0.26	0.55	2.2		
TP12	B581	10.7	4.5	50	49	1	--	--	0.11	0.28			
TP13	D79	4.9	5.2	5	95	0	0.2	0.21	0.31	0.75	1.6		
TP13	D80	4.9	5.2	6	94	0	0.11	0.2	0.3	0.7	2.7		
TP13	D81	4.9	5.2	4	96	0	0.11	0.2	0.25	0.32	2.3		
TP13	D84	12.8	4.9	19	77	4	--	0.12	0.29	1.8			
TP3	D101			10	90	0	--	0.18	0.28	0.7			
TP3A	B543	5.3	1.3	8	92		0.85	0.18	0.4	0.6	0.5		15
TP3A	B544	5.3	1.3	46	54	0	--	--	0.95	0.13			
TP3A	B545	5.3	1.3	25	68	7	--	0.1	0.45	1.7			
TP5A	B550	5.3	2.9	41	59	0	--	--	0.1	0.3			0.49
TP5A	B551	5.3	2.9	27	72	1	--	0.08	0.18	0.4			
TP6	B558	4	5.1	21	77	2	--	0.16	0.35	1			
TP6	B559	4	5.1	11	88	1	0.08	0.2	0.5	1.2	6.3		
TP6	B560	4	5.1	4	96	0	0.13	0.2	0.4	0.65	3.1		
TP8A1	B583	2.1	0.6	9	80	19	0.1	0.28	1.1	3.8	11.0		
TP9	D155	4	0.6	10	47	43	0.09	0.37	6.2	28	68.9		
MAX		12.8	6	50	99	43	8.6	1.5	6.5	28	68.9	0	15
MIN		0	0.6	1	47	0	0	0	0.1	0.13	0.5		0.49
AVE		3.78	3.93	15.32	81.94	2.89	0.196	0.167	0.49	1.74	5.3	1	7.74
NUM		25	25	68	68	67	68	68	68	68	31.0	0	2

TABLE B-4

GROUND ENGINEERING LTD. DATA, KEY LAKE SILT

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) SILT	SAND	GRAVEL	GRAIN SIZE D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	COEFFICIENT OF UNIFORMITY	WATER CONTENT (%)	PERMEABILITY (X10+5 m/s)
TH3	D184A			56	44	0	--	--	0.091	0.24			
TH3	D184B			73	27	0	--	--	--	0.2			
TM36	D176			56	37	7	--	--	0.09	0.27			
TP13	D83	10.1	2.7	65	35	0	--	--	--	0.11			
MAX		10.1	2.7	73	44	7	0	0	0.091	0.27	0.0	0	0
MIN		10.1	2.7	56	27	0	0	0	0	0.11			
AVE		10.1	2.7	62.5	35.75	1.75	0	0	0.045	0.2	1.0	1	1
NUM		1	1	4	4	4	4	4	4	4	0.0	0	0

TABLE B-5
GROUND ENGINEERING LTD. DATA, KEY LAKE TILL

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			GRAIN SIZE				COEFFICIENT OF UNIFORMITY	WATER CONTENT (%)	PERMEABILITY (X10+5 m/s)
				SILT	SAND	GRAVEL	D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)			
TM11	D144			5	95	0	0.16	0.21	0.3	0.7	1.9		
TM43	D129			9	63	28	0.09	0.25	0.8	15	8.9		
TM6	D123			24	50	26	--	0.1	0.6	12			
TP10A	D157	0	10.4	3	23	74	0.27	6.8	21	32	77.8		
TP10A	D158	0	10.4	1	9	90	4	22	28	34	7.0		
TP10A	D160	0	10.4	6	87	7	0.12	0.21	0.35	1.1	2.9		
TP10A	D161	0	10.4	4	52	44	0.18	0.29	10.1	28	56.1		
TP11	B565	5.5	5.2	1	94	4	0.19	0.28	0.65	1.8	3.0	18	
TP11	B566	5.5	5.2	2	87	11	0.19	0.29	1	3.2	5.3		
TP11	B566	5.5	5.2	2	87	1		0					
TP11	B567	5.5	5.2	9	32	59	0.1	1.4	8	17	80.0		
TP11	B569	11.9	0.3	19	39	42	--	0.25	4.5	11			
TP11C	B575	6	4.4	8	58	34	0.12	0.26	2	12	16.7		
TP11C	B576	6	4.4	8	68	24	0.1	0.22	0.75	12	7.5		
TP12	B578	1.5	9.2	14	69	17	--	0.2	0.6	5			
TP12	B579	1.5	9.2	17	79	4	--	0.19	0.3	1			
TP12	B580	1.5	9.2	24	63	13	--	0.095	0.23	2			
TP13	D85	17.7	1.5	4	37	59	0.28	2.3	9	18	32.1		0.88
TP3A	B546	6.3	5.6	8	44	48	0.11	0.4	8	18	72.7		
TP3A	B547	6.3	5.6	3	15	82	0.4	9	15	18	37.5		
TP3A	B547	6.3	5.6	3	15	82	0.4	9	15	18			5.8
TP5	B548	8.2	3.4	13	61	26	--	0.3	1.2	12			1.4
TP5A	B549	8.2	3.4	1	79	20	0.3	0.6	1.9		6.3		
TP9	D156	4.6	5.4	12	78	10	--	0.2	0.6	2.3			
MAX		17.7	10.4	24	95	90	4	22	28	34		18	5.8
MIN		0	0.3	1	9	0	0	0	0.23	0.7	1.9	18	0.88
AVE		5.14	6.17	8.33	57.66	33.54	0.3	2.285	5.64	12.45		18	2.69
NUM		21	21	24	24	24	23	24	23	22	16.0	1	3

TABLE B-6
BAYROCK SURFICIAL GEOLOGY, KEY LAKE ESKER

SAMPLE NUMBER	GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	DESCRIPTION
KL-76- 78-1	0	0	100	0	VERY COARSE SAND
KL-76- 84-1	0	0	85	15	COARSE SAND
KL-76- 18-1	3	3	41	53	SILTY, GRAVELLY SAND
KJ-76- 71-1	0	0	100	0	FINE SAND
KJ-76- 75-2	0	0	91	9	VERY COARSE SAND
KI-76- 18-1	6	1	93	0	MEDIUM CLAYEY SAND
KI-76- 21-1	5	3	87	5	SILTY, COARSE SAND
MAX	6	3	100	53	
MIN	0	0	41	0	
AVE	2	1	85.28	11.71	
NUM	7	7	7	7	

TABLE B-7
BAYROCK SURFICIAL GEOLOGY, KEY LAKE KAME MORAINE

SAMPLE NUMBER	GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	DESCRIPTION
KL-76- 80-1	0	0	88	12	GRAVELLY SAND
KJ-76- 88-1	0	0	71	29	GRAVELLY SAND
KJ-76- 92-1	6	1	93	0	CLAYEY SAND
KJ-76- 56-1	0	0	61	39	GRAVELLY SAND
KJ-76- 58-1	6	1	93	0	CLAYEY, FINE SAND
KJ-76- 60-1	0	0	78	22	CLEAN, GRAVELLY SAND
KJ-76- 61-1	0	0	100	0	CLEAN SAND
KJ-76- 85-1	0	0	100	0	MEDIUM SAND
KJ-76- 87-1	0	0	100	0	COARSE SAND
MAX	6	1	100	39	
MIN	0	0	61	0	
AVE	1.33	0.22	87.11	11.33	
NUM	9	9	9	9	

TABLE B-8
BAYROCK SURFICIAL GEOLOGY, KEY LAKE OUTWASH

SAMPLE		GRADATION (% by weight)				DESCRIPTION
NUMBER		CLAY	SILT	SAND	GRAVEL	
KL-76-	54-3	4	8	62	26	DIRTY, GRAVELLY SAND
KL-76-	55-1	0	0	100	0	YELLOW SAND
KL-76-	70-1	0	0	100	0	SAND
KL-76-	76-1	0	0	100	0	FINE SAND
KL-76-	31-1	0	0	94	6	COARSE, CLEAN SAND
KL-76-	32-1	0	0	100	0	CLEAN, MEDIUM SAND
KL-76-	33-1	4	1	62	33	CLAYEY, GRAVELLY SAND
KL-76-	35-1	0	0	72	28	GRAVELLY SAND
KL-76-	36-1	0	0	97	3	SAND WITH PEBBLES
KL-76-	37-1	0	0	100	0	MEDIUM SAND
KL-76-	39-1	0	0	100	0	MEDIUM SAND
KL-76-	40-1	5	3	86	6	CLAYEY SAND, PEBBLES
KL-76-	2-1	0	0	79	21	GRAVELLY SAND
KL-76-	3-1	0	0	100	0	SAND WITH PEBBLES
KL-76-	5-1	0	0	91	9	COARSE SAND, PEBBLES
KL-76-	7-1	0	0	96	4	VERY COARSE SAND
KL-76-	10-1	0	0	94	6	COARSE SAND
KL-76-	12-1	0	0	87	13	GRAVELLY SAND
KL-76-	15-1	0	0	100	0	FINE SAND
KL-76-	23-1	6	18	76	0	CLAYEY, SILTY SAND
KL-76-	29-1	7	3	86	4	COARSE, CLAYEY SAND
KJ-76-	54-1	0	0	100	0	FINE, YELLOW SAND
KJ-76-	68-1	0	0	97	3	YELLOW SAND
KJ-76-	70-1	0	0	100	0	FINE, YELLOW SAND
KJ-76-	73-1	5	0	86	9	CLAYEY SAND, PEBBLES
KJ-76-	75-1	0	0	100	0	FINE SAND
KJ-76-	77-1	0	0	48	52	CLEAN, SANDY GRAVEL
KJ-76-	80-1	0	0	100	0	YELLOW SAND
KJ-76-	81-1	0	0	100	0	CLEAN SAND
KJ-76-	83-1	6	1	93	0	FINE, CLAYEY SAND
KJ-76-	84-1	6	1	93	0	FINE, CLAYEY SAND
KJ-76-	4-1	4	4	40	52	SILTY, ROCKY SAND
KJ-76-	5-1	6	3	85	6	CLAYEY SAND, PEBBLES
KJ-76-	8-1	5	2	93	0	CLAYEY SAND
KJ-76-	10-1	0	0	100	0	FINE SAND
KJ-76-	17-1	7	9	84	0	SILTY, CLAYEY SAND
KJ-76-	19-1	0	0	100	0	FINE, YELLOW SAND
KJ-76-	21-1	6	1	87	6	MEDIUM, CLAYEY SAND
KJ-76-	27-1	8	40	52	0	SILTY SAND
KJ-76-	29-1	7	23	70	0	SILTY SAND

TABLE B-8
BAYROCK SURFICIAL GEOLOGY, KEY LAKE OUTWASH (cont'd.)

SAMPLE NUMBER		GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	DESCRIPTION
KJ-76-	39-1	0	3	92	5	COARSE SAND
KJ-76-	43-1	0	0	100	0	ORANGE SAND
KI-76-	50-1	0	0	100	0	CLEAN, FINE SAND
KI-76-	56-1	0	0	100	0	CLEAN, YELLOW SAND
KI-76-	73-1	5	2	86	7	SILTY SAND, PEBBLES
KI-76-	75-1	0	0	83	17	COARSE SAND
KI-76-	2-1	5	2	90	3	CLAYEY SAND, PEBBLES
KI-76-	19-1	0	0	100	0	MEDIUM SAND
KI-76-	23-1	6	7	87	0	V. FINE, SILTY SAND
KI-76-	24-1	0	0	100	0	CLEAN SAND
KI-76-	26-1	0	0	100	0	YELLOW SAND
KI-76-	36-1	0	0	100	0	SAND WITH PEBBLES
U-75-	37-1	0	10	90	0	VERY FINE SAND
U-75-	44-2	0	0	100	0	CLEAN SAND
U-75-	48-1	0	0	100	0	COARSE, WHITE SAND
U-75-	48-2	0	0	100	0	VERY CLEAN SAND
U-75-	50-1	0	0	30	70	CLEAN WHITE GRAVEL
U-75-	51-1	0	5	80	15	WELL GRADED SAND
U-75-	51-2	0	0	100	0	FINE YELLOW SAND
U-75-	53-1	0	0	100	0	VERY CLEAN WHITE SAND
U-75-	7-1	0	0	88	12	YELLOW, CLEAN SAND
U-75-	8-1	0	0	100	0	YELLOW, CLEAN SAND
U-75-	9-1	0	0	90	10	YELLOW, CLEAN SAND
U-75-	11-1	0	0	100	0	FINE, CLEAN SAND
U-75-	30-2	0	0	100	0	FINE, CLEAN SAND
KL-76-	53-1	0	0	92	8	COARSE SAND
KL-76-	42-1	0	0	97	3	VERY COARSE SAND
KL-76-	44-1	0	0	88	12	COARSE SAND, PEBBLES
KL-76-	49-1	0	0	96	4	CLEAN SHARP SAND
KL-76-	50-1	0	0	91	9	COARSE SAND, PEBBLES
KL-76-	51-1	0	0	100	0	YELLOW SAND
KL-76-	52-1	0	0	93	7	SAND WITH PEBBLES
MAX		8	40	100	70	
MIN		0	0	30	0	
AVE		1.41	2.02	90.04	6.51	
NUM		72	72	72	72	

TABLE B-9
BAYROCK SURFICIAL GEOLOGY, KEY LAKE OUTWASH GRAVEL

SAMPLE NUMBER		GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	DESCRIPTION
KI-76-	53-1	0	0	38	62	FINE, SANDY GRAVEL
MAX		0	0	38	62	
MIN		0	0	38	62	
AVE		0	0	38	62	
NUM		1	1	1	1	

TABLE B-10
BAYROCK SURFICIAL GEOLOGY, KEY LAKE SLOPE WASH

SAMPLE NUMBER		GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	DESCRIPTION
KL-76-	54-1	5	15	80	0	VERY FINE, SILTY SAND
KL-76-	54-2	0	0	100	0	SAND
KL-76-	56-1	0	0	100	0	FINE SAND
KI-76-	11-1	5	3	92	0	CLAYEY SAND
KI-76-	12-1	6	3	91	0	CLAYEY SAND
KI-76-	38-1	6	3	91	0	FINE, CLAYEY SAND
KI-76-	12-1	0	0	72	28	VERY COARSE SAND
MAX		6	15	100	28	
MIN		0	0	72	0	
AVE		3.14	3.42	89.42	4	
NUM		7	7	7	7	

TABLE B-11
BAYROCK SURFICIAL GEOLOGY, KEY LAKE TILL

SAMPLE NUMBER	GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	DESCRIPTION
KL-76- 57-1	7	12	57	24	SILTY, GRAVELLY SAND
KL-76- 60-1	6	6	68	20	SILTY, GRAVELLY SAND
KL-76- 62-1	5	10	65	20	SILTY, GRAVELLY SAND
KL-76- 62-2	5	4	69	22	SILTY, GRAVELLY SAND
KL-76- 74-1	4	8	61	27	SILTY, GRAVELLY SAND
KL-76- 72-1	3	10	47	40	ROCKY, SILTY SAND
KL-76- 30-1	4	6	49	41	SILTY, GRAVELLY SAND
KL-76- 43-1	6	12	66	16	SILTY, GRAVELLY SAND
KL-76- 47-1	7	5	74	14	SILTY, GRAVELLY SAND
KJ-76- 90-1	4	6	56	34	SILTY, ROCKY SAND
KJ-76- -1	7	7	73	13	SILTY, GRAVELLY SAND
KL-76- 20-1	5	5	66	24	GRAVELLY, SILTY SAND
KL-76- 24-1	6	9	64	21	SILTY, GRAVELLY SAND
KL-76- 26-1	7	7	69	17	SILTY, ROCKY SAND
KJ-76- 64-1	3	2	45	50	DIRTY, SANDY GRAVEL
KJ-76- 2-1	0	0	100	0	MEDIUM, CLEAN SAND
KJ-76- 12-1	0	0	98	2	FINE SAND
KJ-76- 34-1	2	6	85	7	SILTY SAND, PEBBLES
KJ-76- 37-1	2	7	83	8	SILTY SAND, PEBBLES
KJ-76- 42-1	5	5	62	28	DIRTY, GRAVELLY SAND
KJ-76- 45-1	4	13	56	27	SILTY SAND. PEBBLES
KJ-76- 47-1	5	4	76	15	COARSE, DIRTY SAND
KJ-76- 49-1	5	21	55	19	V. COARSE SAND, SILTY SAND
KI-76- 42-1	4	8	77	11	COARSE, SILTY SAND
KI-76- 44-1	4	6	77	13	SILTY, GRAVELLY SAND
KI-76- 45-1	11	13	60	16	CLAYEY, GRAVELLY SAND
KI-76- 46-1	4	6	75	15	SILTY, GRAVELLY SAND
KI-76- 48-1	28	8	55	9	COARSE, CLAYEY SAND
KI-76- 59-1	6	4	80	10	SILTY, COARSE SAND
KI-76- 60-1	4	10	73	13	SILTY, COARSE SAND
KI-76- 62-1	6	4	82	8	CLAYEY, SAND, PEBBLES
KI-76- 63-1	5	7	77	11	SILTY SAND, PEBBLES
KI-76- 64-1	5	4	81	10	CLAYEY, GRAVELLY SAND
KI-76- 66-1	7	0	93	0	CLAYEY SAND
KI-76- 68-1	5	3	79	13	CLAYEY, GRAVELLY SAND
KI-76- 70-1	6	3	72	19	CLAYEY, GRAVELLY SAND
KI-76- 5-1	6	4	90	0	FINE, CLAYEY SAND
KI-76- 6-1	7	6	78	9	SILTY, GRAVELLY SAND
KI-76- 8-1	7	17	76	0	SILTY SAND
KI-76- 28-1	5	8	45	42	SILTY, GRAVELLY SAND

TABLE B-11
BAYROCK SURFICIAL GEOLOGY, KEY LAKE TILL (cont'd.)

SAMPLE NUMBER		GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	DESCRIPTION
KI-76-	30-1	6	3	91	0	CLAYEY SAND
KI-76-	31-1	5	5	63	27	DIRTY, GRAVELLY SAND
KI-76-	40-1	14	14	60	12	CLAYEY SAND, PEBBLES
U-75-	55-1	0	0	80	20	GRAVELLY SAND
U-75-	56-1	0	6	79	15	YELLOW SAND, PEBBLES
U-75-	57-1	0	0	87	13	COARSE SAND, PINK
U-75-	57-2	0	10	60	30	SILTY SAND, ROCKS
U-75-	36-1	0	20	63	17	SILTY SANDY, PEBBLES
U-75-	38-1	0	70	30	0	YELLOW SILT
U-75-	39-1	0	40	45	15	SILTY SAND, ROCKS
U-75-	40-1	0	8	79	13	YELLOW SAND
U-75-	41-1	0	20	63	17	SILTY SAND, ROCKS
U-75-	42-1	0	9	75	16	SILTY, COARSE SAND
U-75-	44-1	0	5	82	13	SAND, SILT COAT'GR.
U-75-	46-1	0	5	70	25	COARSE SAND, ROCKS
U-75-	46-2	0	8	74	18	SAND WITH PEBBLES
U-75-	52-1	0	0	75	25	GRAVELLY SAND
U-75-	53-2	0	0	95	5	VERY CLEAN SAND
U-75-	6-2	0	15	60	25	SILTY SAND, PEBBLES
U-75-	17-1	2	8	47	43	SANDY GRAVEL
U-75-	21-1	0	7	78	15	WELL GRADED SAND
U-75-	22-2	0	5	80	15	FINE, CLEAN SAND
U-75-	24-1	2	6	67	25	SAND, SHARP PEBBLES
U-75-	24-2	2	5	43	50	FINE, SHARP GRAVEL
U-75-	25-1	0	9	68	23	COARSE SAND
U-75-	26-1	0	0	65	35	COARSE SAND
U-75-	28-1	3	10	83	4	GREY, SILTY SAND
U-75-	30-1	0	0	75	25	GRAVELLY SAND
U-75-	31-1	0	7	78	15	COARSE SAND
U-75-	32-1	0	0	75	25	CLEAN, GRAVELLY SAND
U-75-	33-1	0	7	81	12	SILTY SAND, PEBBLES
U-75-	34-1	0	5	85	10	SILTY SAND, PEBBLES
MAX		28	70	100	50	
MIN		0	0	30	0	
AVE		3.55	8.09	70.41	17.93	
NUM		72	72	72	72	

TABLE B-12
SRC DATA, KEY LAKE GRAVEL

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
145111	74G 1	0.9		1	1	98	0.56	GF	H
148111	74G 8	0.4		1	13	86	0.58	GF	H
148311	74G 8	0.5	0.5	0	4	96	0.35	C	T
148311	74G 8	0.8		0	4	96	0.35	C	T
149811	74G 1	0.5		0	9	91	0.27	GF	H
173411	74H 4	0.3	0.5		1	99	0.9	GF	
95511	74H 3	0.9		0	1	99	1.2	GF	R
	MAX	0.9	0.5	1	13	99	1.2		
	MIN	0.3	0.5	0	1	86	0.27		
	AVE	0.61	0.5	0.33	4.71	95	0.6		
	NUM	7	2	6	7	7	7		

TABLE B-13
SRC DATA, KEY LAKE SAND

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
102711	74H 5	1.1		1	7	92	0.14	GF	P
144911	74G 8	1				100	0.29	GF	H
145011	74G 1	1				100	0.4	GF	H
145021	74G 1	1.3				100	0.36	GF	H
147811	74G 8	0.8				100	0.32	GF	K
148011	74G 8	0.5		2	8	90	0.3	GL	T
148411	74G 8	0.6		2	8	90	0.27	GF	P
148511	74G 8	0.4			10	90	0.28	GF	P
148611	74G 8	0.7		1		99	0.58	GF	
149911	74G 1	0.3	0.3		11	89	0.78	M	H
150011	74G 1	1				100	0.45	GF	H
150111	74G 1	1			1	99	0.34	GF	H
150211	74G 1	1				100	0.43	GF	H
151511	74G 8	0.5			14	86	0.28	GF	T
170211	74G 8	0.3	0.5	0	3	97	0.77	GF	R
170221	74G 8	0.6		0	0	100	0.5	GF	R
170311	74G 1	1							
173421	74H 4	1			2	98	1.5	GF	
173511	74H 4	50	60			100	0.53	GF	H
232010	74H 4	4	4					GF	
93411	74H 4	0.9		1	1	98	0.54	GF	P
93511	74H 4	1.2		2	1	97	0.53	GF	P
93611	74H 4	0.7		2	10	88	0.43	GF	H
93811	74H 4	0.8		1	7	92	0.26	GF	
94411	74H 5	0.6			2	98	0.2	GL	P
94711	74H 5	0.6		7	39	54	0.2	GL	
95011	74H 3	0.8		1	1	98	0.58	GF	H
95111	74H 3	0.8		2	27	71	0.12	GL	P
95811	74H 3	0.8			2	98	0.32	GF	R
96311	74H 4	0.9		0	2	98	0.23	GF	R
96411	74H 4	0.8		0	3	97	0.41	GF	H
96511	74H 4	1.4		0	3	97	0.17	GL	
96611	74H 4	0.8		1	0	99	0.41	GF	R
97011	74H 6	0.6		1	27	72		GF	
97111	74H 6	0.6		0	11	89	0.17	GF	P
97311	74H 6	0.8		1	5	94	0.21	GF	
97411	74H 6	0.7		1	6	93	0.18	GL	
	MAX	50	60	7	39	100	1.5		
	MIN	0.3	0.3	0	0	54	0.12		
	AVE	2.21	16.2	1.23	7.81	93.22	0.39		
	NUM	37	4	21	27	35	34		

TABLE B-14
SRC DATA, KEY LAKE SILT

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
				CLAY	SILT	SAND			
94111	74H 5	0.6		3	76	21	0.06	GF	D
94511	74H 5	0.6		3	77	20	0.68	GL	
94811	74H 5	0.6		5	80	15	0.07	GL	
96111	74H 3	0.9		1	51	48	0.14	GL	
	MAX	0.9	0	5	80	48	0.68		
	MIN	0.6		1	51	15	0.06		
	AVE	0.67	1	3	71	26	0.23		
	NUM	4	0	4	4	4	4		

TABLE B-15
SRC DATA, KEY LAKE TILL

SITE	NTS	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
101611	74H 6	0.6		2	12	86	0.36	M	
145211	74G 1	0.6	0.6	1	53	46	0.19	M	
145221	74G 1	0.9			9	91	0.23	M	
145311	74G 1	0.3		2	7	91	0.29	M	D
147711	74G 8	0.5		2	16	82	0.27	M	D
148021	74G 8	0.5						GL	T
148211	74G 8	0.5		1	34	65	0.25	M	D
149711	74G 1	0.5		2	26	72	0.27	M	R
149921	74G 1	0.6		0	9	91	0.28	M	H
231921	74H 4	2	3	2	6	92	0.39	M	
231922	74H 4	3	.	0	6	94	0.43	M	
232021	74H 4	4.5	.	4	36	60	0.2	GF	
232031	74H 4	5	.	1	9	90	0.34	GF	
232111	74H 4	10	.	2	8	90	0.38	M	D
232211	74H 4	10	.	6	12	82	0.41	M	D
232311	74H 4	2	2	3	25	72	0.46	M	D
232321	74H 4	2.5	.	3	10	87	0.23	M	D
93211	74H 4	0.5		4	14	82	0.23	M	
93311	74H 4	0.8		3	7	90	0.22	M	R
93711	74H 4	0.5		1	2	97	0.3	M	R
93911	74H 4	0.7		1	9	90	0.38	R	R
94011	74H 5	0.6		2	16	82	0.19	M	D
94211	74H 5	0.6		2	23	75	0.19	M	H
94311	74H 5	0.7		1	26	73	0.18	M	H
94611	74H 5	0.5		0	14	86	0.18	M	H
94911	74H 5	0.6		1	22	77	0.24	M	R
95211	74H 3	0.8		2	23	75	0.15	M	D
95221	74H 3	0.8		2	13	85	0.52	M	D
95311	74H 3	0.7		2	14	84	0.49	M	P
95411	74H 3	0.7		1	5	94	0.23	M	P
95711	74H 3	0.9		2	38	60	0.55	M	V
95911	74H 3	0.8			18	82	0.48	M	
96711	74H 6	0.7		1	12	87	0.57	M	D
96811	74H 6	0.6		1	17	82	0.28	M	R
97211	74H 6	0.8		4	38	58	0.24	M	R
97511	74H 6	0.8		1	9	90	0.28	M	R
97611	74H 6	0.7		1	7	92	0.35	M	R
	MAX	10	3	6	55	97	0.57		
	MIN	0.3	0	0	2	39	0.15		
	AVE	1.57	0.76	1.94	17.65	80.5	0.31		
	NUM	38	10	36	38	38	38		

TABLE B-16
CLIFTON ASSOCIATES LTD. DATA, KEY LAKE TILL

TEST HOLE	GRADATION (% by weight)			GRAIN SIZE				COEFFICIENT OF UNIFORMITY	WATER CONTENT (%)	UNIT WEIGHT (kN/m3)	SPECIFIC GRAVITY
	SILT	SAND	GRAVEL	D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)				
M107	14	68	18		0.2	0.5	12	0.5	4.2	18.2	2.68
C759	15	80	5		0.18	0.3	1.5	0.3	4	17.8	2.68
MAX	15	80	18		0.2	0.5	12	0.5	4.2	18.2	2.68
MIN	14	68	5		0.18	0.3	1.5	0.3	4	17.8	2.68
AVE	14	74	11		0.19	0.4	6.8	0.4	4.1	18	2.68
NUM	2	2	2		2	2	2	2	2	2	2

TABLE B-17
CLIFTON ASSOCIATES LTD. DATA, KEY LAKE SAND

TEST HOLE	GRADATION (% by weight)			GRAIN SIZE				COEFFICIENT OF UNIFORMITY	WATER CONTENT (%)	UNIT WEIGHT (kN/m3)	SPECIFIC GRAVITY
	SILT	SAND	GRAVEL	D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)				
C765	8	65	27	0.1	0.2	0.6	80	6	4.2	18.2	2.68
MAX	8	65	27	0.1	0.2	0.6	80	6	4.2	18.2	2.68
MIN	8	65	27	0.1	0.2	0.6	80	6	4.2	18.2	2.68
AVE	8	65	27	0.1	0.2	0.6	80	6	4.2	18.2	2.68
NUM	1	1	1	1	1	1	1	1	1	1	1

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APPENDIX "C"

APPENDIX C

RABBIT LAKE STUDY AREA DATA

The Rabbit Lake Study Area is shown on Figure C-1. This map shows the surficial geology and some glacial features. Figure C-2 defines symbols and geological units on the map.

Information on the Rabbit Lake Study Area was obtained from the following publications. A full listing of the references is found in the References of this report.

- Schreiner, B.T., 1984
- Gulf Minerals Canada Limited, 1980a, 1980b
- Gulf Minerals Canada Limited, 1981a
- Gulf Minerals Canada Limited, 1981b
- Gulf Minerals Canada Limited, 1981c
- Canada Wide Mines Ltd., 1981
- MacLaren Engineers, 1984

A summary of data for this study area can be found in Table 7-2 of the main report.

Data on the following tables has been categorized according to the geologic unit or textural classification. For each collection of data, maximum minimum, average values and number of measurements made are tabulated.

LEGEND

Terrain Classification

GEOMORPHIC MODIFIER	ENVIRONMENT CATEGORIES						
	R ROCK	M MORAINAL	A ALLUVIAL	GF GLACIOFLUVIAL	GL GLACIO LACUSTRINE	O ORGANIC	E EOLIAN
c concealed	obscured only by vegetation	——	——	——	——	——	stabilized by vegetation
w weathered	frost-broken (felsenmeer)	winnowed, "washed" and subdued by wave action				——	blowouts
e eroded	ice scoured	channelled by former streams of glacial meltwater, in a braided or parallel pattern				——	——
g gullied	——	dissected by modern ravines in a dentritic pattern					
k collapsed	karst	kettled	——	kettled	kettled	——	——
p plain	plain	plain	floodplain	outwash plain	plain	bog	plain
v veneer	——	thin enough — usually less than 3 metres thick — to reveal geomorphic fabric of underlying formation					
r ridged	corrugated with parallel stratification ridges, igneous and tectonic foliation	transverse elements, end, minor moraines	point bars	eskerine complex	beach berms strandlines and wave-cut benches	string bog	dunes
h hummocky	——	ablational and chaotic disintegration moraines	——	hummocky terrain, kames, kettles	——	palsa	dunes
d drumlinoid	——	longitudinal elements drumlins, flutings, crag and tail hills	——	——	——	——	——
t terrace	——	terrace bench	terrace bench	kame terrace	terrace bench	——	——

Example: Glaciolacustrine plain

GL p

Environment Category — Geomorphic Modifier

FIGURE C-2

TABLE C-1
SRC DATA, RABBIT/MIDWEST LAKE GRAVEL

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
106811	74H 16	0.8		0	1	99	0.68	GF	H
237111	74I 1	0.4	.	0	1	99	1.18	GF	P
238011	74I 2	0.8	.	2	2	96	0.23	GF	RH
239611	74I 8	0.7	.	0	0	100	1.07	M	D
251510	64L 4	0.6	.					R	R
253011	64L 5	0.6	0.8	0	1	99	0.66	GF	P
253710	64L 5	.	.					GF	R
254511	64L 4	2.5	3	1	18	81	0.95	GF	
260811	74I 8	0.5	.	0	1	99	1.17	M	D
261911	64L 5	0.6	.	2	3	95	1.15	M	V
	MAX	2.5	3	2	18	100	1.18		
	MIN	0	0	0	0	81	0.23		
	AVE	0.75	0.42	0.62	3.37	96	0.88		
	NUM	10	9	8	8	8	8		

TABLE C-2
SRC DATA, RABBIT/MIDWEST LAKE PEAT

SITE	NT S		DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
					CLAY	SILT	SAND			
174011	64L	4	1	1					O	P
252910	64L	5	0.1	.					O	P
255711	64L	4	0.5	.					O	H
256711	64L	4	0.5	.					O	P
256911	74I	1	0.5	.					O	P
259211	64L	5	0.3	.					O	P
	MAX		1							
	MIN		0.1	.						
	AVE		0.48							
	NUM		6	0	0	0	0	0		

TABLE C-3
SRC DATA, RABBIT/MIDWEST LAKE SAND

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
105411	74H 15	0.6		0	3	97	0.45	GF	
105511	74H 15	1		1	0	99	0.7	GF	P
106011	74H 15	0.8		0	2	98	0.17	GF	R
106111	74H 15	0.8		0	2	98	0.27	GF	R
106711	74H 16	0.9		1	0	99	0.57	GF	H
238211	74I 2	0.7	.	1	6	93	0.21	GF	H
238411	74I 7	0.8	.	0	0	100	0.19	GF	H
238511	74I 7	1	.			100	0.59	GF	R
238911	74I 7	0.8	.	0	2	98	0.26	M	D
239511	74I 8	0.3	.	2	33	65	0.13	GF	P
240511	74I 7	0.7	.	0	0	100	0.58	GF	P
249511	64L 3	0.5	.	1	28	71	0.08	GF	R
251311	64L 4	0.7	.	0	1	99	0.51	GF	H
252821	64L 5	1.1	.	0	0	100	0.23	M	
254111	64L 6	0.6	.	0	1	99	0.17	GF	R
254211	64L 6	0.5	.	1	14	85	0.1	GF	R
254911	64L 4	1.5	.	2	2	96	0.11	GL	V
255311	64L 4	1	1	3	37	60	0.08	O	H
255511	64L 4	0.8	1	0	0	100	0.35	GF	R
255521	64L 4	1.1	0.1	1	2	97	0.63	GF	R
255531	64L 4	1.5	.	2	3	95	0.13	GF	R
255532	64L 4	2.5	.	2	3	95	0.13	GF	R
256411	64L 4	0.6	0.8	5	5	90	0.1	GF	V
257211	74I 1	1	.	2	17	81	0.08	GF	P
257711	74I 1	0.4	.	1	11	88	0.25	GF	H
257911	74I 1	1	.			100	0.46	GF	H
258011	74I 1	0.7	.	3	3	94	0.12	GF	H
258511	74I 8	1	.			100	0.57	GF	R
259011	64L 5	1	.	0	0	100	0.22	GF	V
259911	74I 8	0.8	.	3	3	94	0.14	M	D
260911	74I 8	0.6	.	2	2	96	0.34	M	D
	MAX	2.5	1	5	37	100	0.7		
	MIN	0.3	0	0	0	60	0.08		
	AVE	0.88	0.11	1.17	6.42	93.12	0.28		
	NUM	31	26	28	28	31	31		

TABLE C-4
SRC DATA, RABBIT/MIDWEST LAKE SILT

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
249011	64L 3	0.3	.	2	63	35	0.08	R	RW
251411	64L 4	0.3	.	2	54	44	0.08	R	R
252311	64L 4	0.2	0.2	2	61	37	0.08	R	R
254611	64L 4	0.2	0.2	4	65	31	0.08	E	V
	MAX	0.3	0.2	4	65	44	0.08		
	MIN	0.2	0	2	54	31	0.08		
	AVE	0.25	0.1	2.5	60.75	36.75	0.08		
	NUM	4	4	4	4	4	4		

TABLE C-5
SRC DATA, RABBIT/MIDWEST UPPER TILL

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
105811	74H 15	0.7		2	20	78	0.21	M	R
106911	74H 16							M	H
123411	64L 4	1.6	9	6	22	72	0.57	M	P
123412	64L 4	4	9	1	14	85	0.57	M	P
123413	64L 4	5.2	9	5	25	70	0.71	M	P
123414	64L 4	6.4	9	3	23	74	0.54	M	P
135221	64L 4	4		3	18	79	0.66	M	
173611	64L 4	3		0	3	97	0.66	M	
173731	64L 4	2.3		0	24	76	0.21	M	
237811	74I 2	0.5	.	1	14	85	0.08	M	P
238611	74I 7	0.5	.	1	9	90	0.33	M	PT
239211	74I 8	0.6	.	2	17	81	0.31	M	P
239411	74I 8	0.7	.	1	14	85	0.46	M	P
249911	64L 6	0.3	.	1	40	59	0.42	R	R
251711	64L 4	0.7	.	2	17	81	0.49	M	D
252111	64L 4	0.7	.	1	29	70	0.49	M	R
252211	64L 4	0.6	.	1	23	76	0.56	M	P
252511	64L 5	0.6	.	1	15	84	0.41	M	VD
253811	64L 5	0.6	.	1	13	86	0.18	M	H
255011	64L 4	0.5	0.6	5	54	41	0.25	M	
255211	64L 4	0.8	2	1	20	79	0.34	M	
255611	64L 4	0.7	.	1	15	84	0.53	M	D
256211	64L 4	0.5	.	1	11	88	0.63	M	H
256311	64L 4	0.5	.	2	2	96	0.47	O	P
256811	64L 4	0.7	.	1	20	79	0.44	M	D
257811	74I 1	1	.	4	4	92	0.52	M	R
258211	74I 1	0.7	.	3	3	94	0.19	M	H
258411	74I 8	0.5	.	2	31	67	0.42	M	H
258711	74I 8	0.6	.	1	21	78	0.39	M	H
258911	64L 5	0.5	.	1	20	79	0.33	M	D
260511	74I 8	0.6	.	1	21	78	0.4	M	H
260711	74I 8	0.7	.	1	6	93	0.41	M	D
261011	64L 5	0.5	.	1	2	97	0.83	R	W
261111	64L 5	0.5	.	1	14	85	0.34	M	H
261311	64L 5	0.5	.	0	1	99	0.71	M	V
261411	64L 5	0.5	.	1	11	88	0.62	M	D
261511	64L 5	1	.	0	0	100	0.97	M	D
261611	64L 5	0.4	.	1	25	74	0.33	M	P
262011	64L 5	0.4	.					M	P
106411	74H 16	0.6		0	16	84	0.26	M	V

TABLE C-5
SRC DATA, RABBIT/MIDWEST UPPER TILL (cont'd.)

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
106511	74H 16	0.6		1	19	80	0.25	M	R
106611	74H 16	0.5		0	22	78	0.27	M	P
135311	64L 4	3	4	3	44	53	0.33	M	
173721	64L 4	1.2	2	7	35	58	0.28	M	
173821	64L 4	1.2	1	3	35	62	0.68	M	
173921	64L 5	1.5		6	21	73	0.38	M	
237211	74I 1	0.8	.	1	19	80	0.23	M	D
237911	74I 2	0.6	.	2	15	83	0.26	M	H
238111	74I 2	0.6	.	3	26	71	0.14	M	H
238711	74I 7	0.5	.	2	11	87	0.46	M	D
238811	74I 7	0.4	.	2	11	87	0.23	M	D
239011	74I 7	0.6	.	1	11	88	0.26	M	D
239111	74I 8	0.7	.	1	15	84	0.26	M	D
239711	74I 8	0.6	.	2	25	73	0.27	M	D
239811	74I 8	0.7	.	1	27	72	0.32	M	P
239911	74I 8	0.5	.	1	20	79	0.3	M	D
240011	74I 8	0.6	.	3	14	83	0.38	M	D
251611	64L 4	0.6	.	16	17	67	0.32	M	P
251811	64L 4	0.6	.	0	20	80	0.32	M	P
251911	64L 4	0.5	.	1	12	87	0.51	M	P
252411	64L 5	0.7	.	3	39	58	0.36	R	R
253021	64L 5	1	.	1	19	80	0.56	GF	P
253111	64L 5	0.5	.	0	20	80	0.42	M	V
253611	64L 5	0.5	.	2	21	77	0.44	M	V
254521	64L 4	5	.	4	23	73	0.64	GF	
254631	64L 4	0.8	.	1	6	93	0.89	E	V
254632	64L 4	1.3	.	10	74	16	.	E	V
254633	64L 4	1.8	.	1	10	89	0.27	E	V
255112	64L 4	0.9	1	1	18	81	0.55	M	
255121	64L 4	1.2	.	5	31	64	0.5	M	
255122	64L 4	1.8	.	2	16	82	0.41	M	
255811	64L 4	0.6	.	3	69	28	0.1	M	H
256121	64L 4	1	.	2	33	65	0.36	M	V
256421	64L 4	0.9	.	7	7	86	0.22	GF	V
256511	64L 4	1	.	4	5	91	0.31	M	D
257611	74I 1	1	.	1	5	94	0.42	M	H
258111	74I 1	0.5	.	1	22	77	0.36	M	P
259111	64L 5	0.5	.	0	1	99	0.37	M	H
259711	64L 5	0.8	.	1	22	77	0.38	M	P
259811	64L 5	0.6	.	1	9	90	0.44	M	V

TABLE C-5
SRC DATA, RABBIT/MIDWEST UPPER TILL (cont'd.)

SITE	NT	S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
					CLAY	SILT	SAND			
257411	74I	1	0.5	.	2	27	71	0.24	M	H
259611	64L	5	1	.	2	62	36	0.2	M	H
237011	74I	1	0.5	.	2	14	84	0.4	M	P
254711	64L	4	1.5	.	6	25	69	0.56	M	V
255221	64L	4	2.5	.	5	26	69	0.58	M	
258811	64L	5	1	.	1	18	81	0.48	O	P
259411	64L	5	1	.	1	1	98	0.24	M	H
238311	74I	2	0.5	.	2	11	87	0.27	M	H
238311	74I	2	0.5	.	2	11	87	0.27	M	H
257111	74I	1	0.6	.	1	11	88	0.44	M	D
257111	74I	1	0.6	.	1	11	88	0.44	M	D
257311	74I	1	0.5	.	0	8	92	0.4	M	V
257311	74I	1	0.5	.	0	8	92	0.4	M	V
257511	74I	1	0.5	.	1	14	85	0.46	M	P
257511	74I	1	0.5	.	1	14	85	0.46	M	P
259311	64L	5	0.4	.	1	15	84	0.39	R	W
259311	64L	5	0.4	.	1	15	84	0.39	R	W
259511	64L	5	0.5	.	0	10	90	0.37	M	PD
259511	64L	5	0.5	.	0	10	90	0.37	M	PD
260211	74I	8	0.4	.	1	15	84	0.47	M	P
260211	74I	8	0.4	.	1	15	84	0.47	M	P
260311	74I	8	0.8	.	3	13	84	0.2	M	H
260311	74I	8	0.8	.	3	13	84	0.2	M	H
260411	74I	8	0.5	.	1	12	87	0.27	R	W
260411	74I	8	0.5	.	1	12	87	0.27	R	W
260611	74I	8	0.3	.	1	17	82	0.31	M	D
260611	74I	8	0.3	.	1	17	82	0.31	M	D
261811	64L	5	0.3	.	2	51	47	0.22	M	D
261811	64L	5	0.3	.	2	51	47	0.22	M	D
105611	74H	15	0.8		1	5	94	0.27	M	D
105711	74H	15	1		1	26	73	0.2	M	V
105911	74H	15	0.6		1	20	79	0.22	M	V
106211	74H	15	0.7		2	20	78	0.26	M	
106311	74H	16	0.8		0	9	91	0.18	M	
173711	64L	4	0.3	0.5	0	35	65	0.37	M	
173811	64L	4	0.3	0.5	3	36	61	0.47	M	
173911	64L	5	0.1	0.2	0	7	93	0.15	M	
237311	74I	1	0.6	.	1	9	90	0.23	M	P
237511	74I	1	0.7	.	1	18	81	0.21	M	PD
237611	74I	1	0.6	.	2	19	79	0.38	M	PD

TABLE C-5
SRC DATA, RABBIT/MIDWEST UPPER TILL (cont'd.)

SITE	NT	S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight) CLAY	SILT	SAND	MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
237711	74I	1	0.6	.	2	19	79	0.32	M	PD
239311	74I	8	0.7	.	0	13	87	0.26	M	P
249611	64L	3	0.7	.	1	29	70	0.21	R	R
249811	64L	6	.	0.5	3	35	62	0.26	R	L
254621	64L	4	0.3	0.5	1	21	78	0.61	E	V
254622	64L	4	0.6	0.5	1	13	86	0.35	E	V
255111	64L	4	0.6	1	1	12	87	0.49	M	
255911	64L	4	0.5	.	1	9	90	0.5	M	D
256011	64L	4	0.6	.	1	7	92	0.25	M	H
256111	64L	4	0.7	0.7	1	10	89	0.2	M	V
256611	64L	4	0.5	.	1	14	85	0.41	M	PD
257011	74I	1	0.6	.	3	3	94	0.42	M	H
260111	74I	8	0.7	.	1	16	83	0.27	M	D
261711	64L	5	0.8	.	1	22	77	0.59	M	P
	MAX		6.4	9	16	74	100	0.97		
	MIN		0	0	0	0	16	0		
	AVE		0.88	0.43	1.82	18.66	79.51	0.37		
	NUM		134	121	133	133	133	133		

TABLE C-6
SRC DATA, RABBIT/MIDWEST LOWER TILL

SITE	NT S	DEPTH (m)	THICKNESS (m)	GRADATION (% by weight)			MEDIAN DIAMETER (mm)	TERRAIN CLASSIFICATION	
				CLAY	SILT	SAND			
237411	74I 1	0.9	.	1	17	82	0.21	M	PD
249111	64L 3	0.4	.	1	13	86	0.88	R	R
251521	64L 4	0.6	.	3	67	30	0.21	R	R
252811	64L 5	0.4	1	0	15	85	0.4	M	
254411	64L 6	0.2	.	2	39	59	0.24	R	R
258611	74I 8	1	.	1	8	91	0.4	M	H
261211	64L 5	.	.	1	1	98	0.87	M	D
123422	64L 4	9.6	8	4	28	68	0.57	M	P
123422	64L 4	9.6	8	4	28	68	0.57	M	P
173831	64L 4	1.5		9	37	54	0.39	M	
173831	64L 4	1.5		9	37	54	0.39	M	
252011	64L 4	0.5	.	1	19	80	0.33	M	D
252011	64L 4	0.5	.	1	19	80	0.33	M	D
255021	64L 4	1	.	12	36	52	0.41	M	
255021	64L 4	1	.	12	36	52	0.41	M	
123421	64L 4	8.2	2.6	3	27	70	0.31	M	P
123423	64L 4	10.6	8	4	25	71	0.48	M	P
135211	64L 4	3	4	2	17	81	0.18	M	
	MAX	10.6	8	12	67	98	0.88		
	MIN	0	0	0	1	30	0.18		
	AVE	2.8	1.97	3.88	26.05	70.05	0.42		
	NUM	18	16	18	18	18	18		

TABLE C-7
GULF MINERALS CANADA LTD. DATA, COLLINS BAY B-ZONE, SAND

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	STANDARD PENETRATION RESISTANCE	GRADATION (% by weight) CLAY	SILT	SAND	GRAVEL	GRAIN SIZE D10	D30	D60	D85	COEFFICIENT OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
1-7		0.2	0.9	100										
1-8		7	3.7											1
1-9		6.3	1.8	43										
1-10		0	2.3	100										6
1-11		0.3	6.8	25										
1-12		0	1.2	100										
1-13		0.3	3.4	100										
1-14		4.3	0.9	11										1
1-19		0.8	1.1	45										
	MAX	7	6.8	100	0	0	0	0	0	0	0	0	0	6
	MIN	0	0.9	11										1
	AVE	2.13	2.45	65	1	1	1	1	1	1	1	1	1	2.66
	NUM	9	9	8	0	0	0	0	0	0	0	0	0	3

TABLE C-8
GULF MINERALS CANADA LTD. DATA, COLLINS BAY B-ZONE, SANDY SILT

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	STANDARD PENETRATION RESISTANCE	GRADATION (% by weight)				GRAIN SIZE				COEFFICIENT OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
					CLAY	SILT	SAND	GRAVEL	D10	D30	D60	D85		
1-1		6.8	5	14	5	89	6	0	0	0	0	0	5	0.8
1-3		2.4	1	10	5	65	24	6	0	0	0	0.5	7.777	
1-8		2.5	0.1	5										
1-9		2.1	4.2	2										0.8
1-14		2.6	1.7	28										
1-16		9.1	1.8	1										
1-17		6.1	5.3	17										7
1-18		4.9	4.6	25										2
1-21		1.5	2.4	59										3
	MAX	9.1	5.3	59	5	89	24	6	0	0	0	0.5	7.777	7
	MIN	1.5	0.1	1	5	65	6	0	0	0	0	0	5	0.8
	AVE	4.22	2.9	17	5	77	15	3	0	0	0	0.3	6.388	2.72
	NUM	9	9	9	2	2	2	2	2	2	2	2	2	5

TABLE C-9
GULF MINERALS CANADA LTD. DATA, COLLINS BAY B-ZONE, SILT

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	STANDARD PENETRATION RESISTANCE	GRADATION (% by weight)				GRAIN SIZE				COEFFICIENT OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
					CLAY	SILT	SAND	GRAVEL	D10	D30	D60	D85		
2-2	2	5.6	4.3	25	6	92	2	0	0	0	0	0	6.666	
2-3	3	4.5	7	21	6	90	4	0	0.01	0	0	0	3.833	
2-4		4.1	3.9	26										
2-6	2	14.6	3.8	23	8	91	1	0						
2-7	2	5.3	2.7	31	8	91	1	0	0	0	0	0	5	
2-8		8.1	1.8	25										
2-9	4	5	5.9	16	6	91	3	0						
2-10		4.8	7.5	29										
2-11		4.9	4.1	24										
2-12		4	4	58										
2-13	2	4.1	1.5	100	8	76	14	2	0	0	0	0.1	7	
2-14		5	4.7	23										
2-15		4.2	4.8	20										
2-16		3.7	1.2	32										
	MAX	14.6	7.5	100	8	92	14	2	0.01	0	0	0.1	7	
	MIN	3.7	1.2	16	6	76	1	0	0	0	0	0	3.833	
	AVE	5.56	4.08	32	7	88.5	4.16	0.33	0	0	0	0	5.624	
	NUM	14	14	14	6	6	6	6	4	4	4	4	4	0

TABLE C-10
GULF MINERALS CANADA LTD. DATA, COLLINS BAY B-ZONE, SILT AND PEAT

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	STANDARD PENETRATION RESISTANCE	GRADATION (% by weight)				GRAIN SIZE				COEFFICIENT OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
					CLAY	SILT	SAND	GRAVEL	D10	D30	D60	D85		
2-6	1	4.1	0.3	17	6	54	40	0	0.01	0	0.1	0.1	6	
2-7	1	4.7	0.6	1	4	70	26	0	0.01	0	0	0.1	4	
2-8	3	4.9	3.2	14	6	81	13	0	0.01	0	0	0.1	6.333	
2-9	1	4.7	0.3	1	3	87	10	0	0.01	0	0	0.1	4	
2-10	2	4.4	0.5	2	6	75	19	0	0.01	0	0	0.1	6.6	
2-11		4.2	0.6	12										
2-14	1	4.4	0.6	1	2	68	30	0	0.01	0	0.1	0.1	4.166	
2-16		3.5	0.2											
	MAX	4.9	3.2	17	6	87	40	0	0.01	0	0.1	0.1	6.6	
	MIN	3.5	0.2	1	2	54	10	0	0.01	0	0	0.1	4	
	AVE	4.36	0.78	6.8	4.5	72.5	23	0	0.01	0	0	0.1	5.183	
	NUM	8	8	7	6	6	6	6	6	6	6	6	6	0

TABLE C-11
GULF MINERALS CANADA LTD. DATA, COLLINS BAY B-ZONE, SILTY SAND

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	STANDARD PENETRATION RESISTANCE	GRADATION (% by weight)				GRAIN SIZE				COEFFICIENT OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
					CLAY	SILT	SAND	GRAVEL	D10	D30	D60	D85		
1-2		2.7	11.4	52	2	21	62	15	0.01	0.1	0.4	2	40	2
1-3		3.4	4.8	85	5	27	45	23	0.01	0	0.4	9	57.14	0.5
1-4		0.2	15.5	75	6	36	47	11	0	0	0.2	1.1	33.33	0.9
1-5		0	14.4	100	6	19	45	30	0.01	0.1	1	15	125	4
1-6		0	10.5	60	3	13	62	22	0.02	0.2	0.6	7	30	5
1-7		1.1	2.9	16	2	18	65	15	0.02	0.1	0.3	2	15	6
1-7		5.8	6.7	200										
1-8		3.4	3.7	84	2	47	38	13	0.01	0	0.2	1.5	18.88	0.09
1-9		8.1	4.7	100	4	20	51	25	0.01	0.1	0.6	12	60	0.8
1-10		2.3	8.1	29	1	21	57	21	0.02	0.1	0.5	5	22.5	4.5
1-11		7.2	10.2	100	1	14	62	23	0.03	0.2	0.6	4.5	20	0.06
1-12		1.2	5.3	38	1	43	50	6	0.01	0	0.1	0.4	9	0.5
1-13		3.7	13.1	100	9	44	34	13	0	0	0.2	1.5	60	0.4
1-14		5.2	14.5	100										6
1-15		2.7	8.2	70	2	17	56	25	0.02	0.1	0.9	6	45	0.8
1-18		4.9	3.4	100										2
1-19		1.8	4	45	10	55	29	6	0	0	0.1	0.3	25	0.5
1-19		8.8	3.4	100	6	33	45	16	0.01	0	0.3	2	50	
1-20		1.2	8.5	100	3	23	49	25	0.01	0.1	0.6	7.5	50	1
1-21		4.6	7	100										

TABLE C-11 (CONT'D)
GULF MINERALS CANADA LTD. DATA, COLLINS BAY B-ZONE, SILTY SAND

TEST HOLE	SAMPLE	DEPTH (m)	THICKNESS (m)	STANDARD PENETRATION RESISTANCE	GRADATION (% by weight)				GRAIN SIZE				COEFFICIENT OF UNIFORMITY	PERMEABILITY (X10+5 m/s)
					CLAY	SILT	SAND	GRAVEL	D10	D30	D60	D85		
2-1		5.8	9.8	62										
2-2		9.9	5.4	32										
2-3		11.6	2	100										
2-4	6	8.7	5.8	46	0	12	46	42	—	0.2	3	23	3	
2-5	1	3.4	11.1	60	2	13	43	42	0.02	0.4	4	23	200	
2-6	6	8.2	5.3	48	—	6	32	62	0.13	0.6	30	35	230.7	
2-7	4	8.1	5.8	47	—	4	26	70	0.2	2	18	32	90	
2-8	5	9.9	2.7	66	2	10	28	60	0.03	0.5	7	28	233.3	
2-9		10.8	1.2	85										
2-10	7	12.3	2.9	57	14	26	28	32	—	0	0.7	25	0.7	
2-11		9	3.7	51										
2-12	7	7.9	6.1	22	—	6	76	18	0.08	0.3	0.7	2.6	9.12	
2-13		5.6	2	60										
2-14		8.5	2.4	100										
2-15	4	9	3.7	100	5	16	60	19	0.01	0.2	0.4	4	46.66	
2-16		6.1	7.3	33										
	MAX	12.3	15.5	200	14	55	76	70	0.2	2	30	35	233.3	6
	MIN	0	1.2	16	0	4	26	6	0	0	0.1	0.3	0.7	0.06
	AVE	5.64	6.59	72	3.58	22.7	47.3	26.41	0.03	0.2	2.9	10	61.43	2.06
	NUM	36	36	36	24	24	24	24	24	24	24	24	24	17

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APPENDIX 'D'

APPENDIX D

ELLIOT LAKE STUDY AREA DATA

During the course of this study, a detailed review of published and available unpublished literature was carried out for the purpose of characterizing the soils in the Elliot Lake study area. The main sources of data were from technical publications and unpublished consultants reports pertinent to the area.

To ensure consistency throughout the course of this study, data from each case sutdy were summarized in the tabular form presented here.

The information on the Elliot Lake study area was obtained from the publications and reports listed below with reference numbers noted in the tables following. A full listing of the publications can be found in the References. Figure 8-5 shows the study area. A summary of the data has been shown on Table 8-2 of the main report.

REFERENCE	REFERENCE NO.
Boissonneau, A.N., 1968.	22
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Boyd, J.M., T.G. Carter, R.A. Knapp and K.B. Culver, 1982	
Cherry, J.A., R.A. Blackport, N. Dubrovsky, R.W. Gillham, T.P. Lim, D. Murray, E.J. Reardon and D.J.A. Smyth, 1980.	
Culver, K.B., J.L. Chakravatti, D.M. Gorber, R.A. Knapp and J.B. Davis, 1982.	

REFERENCE (cont'd.)	REFERENCE NO. (cont'd.)
Dave, N.K., T.P. Lim, A.J. Vivyurka, N. Dubrovsky, K.A. Morin, D.J.A. Smyth, R.W. Gillham and J.A. Cherry, 1982.	
Desaulniers, D.E., 1982.	
Dubrovsky, N.M., J.A. Cherry, E.J. Reardon and A.J. Vivyurka, 1985.	21
Golder Associates Eastern (Canada) Ltd., 1981a,b,c,d,e,f.	38, 40, 42, 43, 44, 46.
Golder Associates Eastern (Canada) Ltd., and Senes Consultants Ltd., 1982.	47
H.Q. Golder & Associates Ltd., 1970a,b.	24, 25
H.Q. Golder & Associates Ltd., 1972.	49
H.Q. Golder & Associates Ltd., 1974a,b.	50, 51
H.Q. Golder & Associates Ltd., 1975.	52
H.Q. Golder & Associates Ltd., 1977a,b.	26, 27
H.Q. Golder & Associates Ltd., 1978a,b.	28, 53
H.Q. Golder & Associates Ltd., 1980a,b,c,d,e,f,g,h.	31, 54, 32, 33, 34, 35, 36, 37

REFERENCE (cont'd.)	REFERENCE NO. (cont'd.)
James F. MacLaren Ltd., 1981.	39
James F. MacLaren Ltd. and H.Q. Golder & Associates Ltd., 1978.	29
James F. MacLaren Ltd. and H.Q. Golder & Associates Ltd., 1980a,b.	30, 48
Leech, R.E.J. and Cooper, A.C., 1982	
MacLaren Engineers, Planners and Scientists Inc., Golder Associates Eastern (Canada) Ltd., and Senes Consultants Ltd., 1981.	41
Matyas, E.L., D.E. Welch and D.W. Reades, 1984.	23
Morin, K.A., 1985	
Morin, K.A., J.A. Cherry, T.P. Lim and A.J. Vivyurka, 1982.	18
Myslik, G., 1985.	
Ontario Institute of Pedology, 1983	
Ontario Geological Survey, 1984	20
Quigley, R.M., 1980	

REFERENCE (cont'd.)	REFERENCE NO. (cont'd.)
Reades, D.W., D.P.A. Mangan, J.K. Balins and H.M. Goldby, 1982.	19
Robertson, James A., 1981	
Senes Consultants Ltd. and Golder Associates Eastern (Canada) Ltd., 1981.	45
The Trow Group Limited.	
June 17, 1977.	13
February 21, 1978.	6
March 1, 1978.	16
April 4, 1978.	15
April 11, 1978.	3
April 17, 1978.	5
October 2, 1978.	4
October 10, 1978.	14
October 17, 1978.	12
April 16, 1979.	7
VanDine, D.F., 1980a,b.	
William Trow Associates Limited.	
August 21, 1974.	9
July 24, 1975.	17
January 7, 1976.	8
April 1, 1976.	2
June 30, 1976.	11
August 3, 1976.	1
August 4, 1976.	10

TABLE D-1

DEFINITION OF TABLE SYMBOLS

SYMBOL	DEFINITION
N	Standard Penetration Resistance - L - loose - C - compact - D - dense - VD - very dense
Wp	Plastic Limit
Wl	Liquid Limit
Cc	Coefficient of Curvature
Cu	Coefficient of Uniformity
w	Water Content (%)
Gs	Specific Gravity
n	Porosity (%)
Cc	Compression Index
Cv	Coefficient of Consolidation
k	Permeability
D.T.W.	Depth to Water
*	in situ property
**	compacted property

TABLE D - 2

MATERIAL PROPERTIES FOR ONTARIO SITES

UNIT	AREA	REF	THICK (m)	DESCRIPTION	N	Wp %	Wl %	GRADATION (% by weight) CLAY %	SILT %	SAND %	GRAVEL %	GRAIN SIZE D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	Cc	Cu	UNIT	AREA	REF	w natural %	UNIT WEIGHT (kN/m^3)	Gs	n %	Cc	Cv (cm^2/s)	k SAT (range) (m/s)	k SAT (m/s)	D.T.W. (m)
PEAT	A	NO DATA																PEAT	A	NO DATA									
SILT	A	20		OUTWASH, SILTY POCKETS				0	30	70	0	0.056	0.075	0.11	0.2	0.9	2	SILT	A	20									
SAND	A	20	5	OUTWASH SAND				0	0	50-100	0-50	.4-.59	.84-2	1.7-9	3-50	1-.8	4-15	SAND	A	20									
TILL	A	NO DATA																TILL	A	NO DATA									
PEAT	B	23	0.3	FIBROUS PEAT	27													PEAT	B	23	230						5.0E-07	* *	0.6
PEAT	B	24	0.9	SOFT, BLACK FIBROUS PEAT	9													PEAT	B	24									
PEAT	B	25	0-2.7	V.SOFT BLACK PEAT, S+G	1													PEAT	B	25									
PEAT	B	27	0.76	LOOSE BLACK PEAT	8													PEAT	B	27									
PEAT	B	38	0.3	PEAT														PEAT	B	38									
PEAT	B	50	1.2	PEAT,COMPACTED, Su=192kPa	9													PEAT	B	50									
SILT	B	25	2.7	SAND, TRACE SILT	L - VD													SILT	B	25							1.0E-04		
SILT	B	27		SAND&SILT	VD			9	41	48	2	0.003	0.02	0.15	0.8	0.9	50	SILT	B	27									
SILT	B	50	0.5	SANDY SILT, COBBLES	C			6	80	14	0	0.0036	0.014	0.04	0.08	1.4	11	SILT	B	50									
SAND	B	24	2.3	FINE SAND, TRACE SILT	C - VD			1	9	90	0	0.07	0.17	0.21	0.3	2	3	SAND	B	24							2.0E-04	2.0E-05	
SAND	B	20	3 - 6	OUTWASH				0	15	85	0	0.063	0.177	0.42	0.75	1.4	8	SAND	B	20									
SAND	B	23	>2.5	V.DENSE SAND AND GRAVEL	97													SAND	B	23	32						5.0E-05		
SAND	B	24	15	GLACIOFLUVIAL SAND&GRAVEL	L-VD			2	9	71	20	0.22	0.68	2.5	6.6	0.8	11	SAND	B	24							5.0E-04	1.0E-06	0.6
SAND	B	24		SA+GR,BLDR+COBL	L-VD			0 - 7	1 - 21	57-93	1 - 40							SAND	B	24									
SAND	B	25	8.6	GREY SAND&GRAVEL,BLDR&COBL	L-VD													SAND	B	25							5.0E-05		
SAND	B	27	10.5	GRAVELLY SAND,SOME SILT	C-VD			2	18	50	30	0.025	0.2	2	10.5	0.8	80	SAND	B	27									
SAND	B	31	1.1	COBBLES&BOULDERS,TR. SAND&SILT														SAND	B	31									
SAND	B	36		SAND&GRAVEL,BOULDERS&COBBLES	L-VD			0	5	45	50	0.4	2	10	40	1	2.5	SAND	B	36	6 *	19.8-17.8 **							
SAND	B	41		SAND AND GRAVEL														SAND	B	41							3.0E-05	1.0E-06	
SAND	B	45		QUIRKE LAKE														SAND	B	45							1.0E-05	1.0E-06	
SAND	B	46	6	MED.COARSE SAND&GRAVEL														SAND	B	46									
SAND	B	49	0-21	SILTY SAND/SAND&GRAVEL				0	0 - 23	76-83	1-17	.03-.4	.09-.8	.2-1.5	.7-5	1	7 - 4	SAND	B	49							1.0E-04	1.0E-05	
SAND	B	50	1.5	SAND&GRAVEL, DENSE	D			0	4	20	76	0.5	8	35	60	4	70	SAND	B	50									
SAND	B	51	3	SAND&GRAVEL				1	15	69	15	0.05	0.2	0.9	7	0.9	18	SAND	B	51									
SAND	B	52	1.5															SAND	B	52									2.3

TABLE D - 2 (cont'd)

MATERIAL PROPERTIES FOR ONTARIO SITES

UNIT	AREA	REF	THICK (m)	DESCRIPTION	N	Wp %	Wl %	GRADATION (% by weight) CLAY %	SILT %	SAND %	GRAVEL %	GRAIN SIZE D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	Cc	Cu	UNIT	AREA	REF	w natural %	UNIT WEIGHT (kN/m^3)	Gs	n %	Cc	Cv (cm^2/s)	k SAT (range) (m/s)	k SAT (m/s)	D.T.W. (m)
TILL	B	19+20	<38	SILT AND SAND TILL, GRAVEL&BOULDERS		12	14	5-10	23-33	40-57	0-32	.002-.006	.03-1	.1-2	.5-75	4.5-.8	50-333	TILL	B	19+20	8.5	20.6					9.0E-10	8.0E-04	
TILL	B	27	>7.6	SI-SA TILL, SOME GRAVE	VD	12	17	5	27	56	13	0.007	0.82	0.36	4.5	107	51	TILL	B	27	17								
TILL	B	36	9	BR GREY SI-SA TILL,SOME GRAVEL	L-VD			2-10	19-29	45-60	1-34	.002-.02	.15-.045	.16-2	.6-14	6-.6	80-100	TILL	B	36	8-10	20-20.5**					3.5E-09	2.5E-8**	3.4
TILL	B	38	3-18	SI-SA TILL, OCC. COBBLE &BOULDER	VD													TILL	B	38									1.5
TILL	B	41	27	SI-SA TILL TO SI&SA TILL														TILL	B	41							1.0E-07**	1.0E-9	.5-2.4
TILL	B	46		QUIRKE LAKE														TILL	B	46							1.0E-06	1.0E-08	
TILL	B	50	0.8	SI-SA TILL				6	25	58	11	0.0035	0.03	0.4	3	0.6	114	TILL	B	50									
TILL	B	51	15	SI-SA TILL				10	30	50	10	0.003	0.04	0.25	2	2	83	TILL	B	51	9	20.0-21.5			0.07	0.06	1.0E-06	1.0E-08	3-9
TILL	B	52	1.2-18	SI-SA TILL														TILL	B	52	10						1.0E-06	1.0E-06	7.6
PEAT	C	NO DATA																PEAT	C	NO DATA									
SILT	C	NO DATA																SILT	C	NO DATA									
SAND	C	NO DATA																SAND	C	NO DATA									
TILL	C	NO DATA																TILL	C	NO DATA									
PEAT	D	NO DATA																PEAT	D	NO DATA									
SILT	D	NO DATA																SILT	D	NO DATA									
SAND	D	20	6	OUTWASH AND SAND&GRAVEL				0	0	40	60	0.46	1.3	18	35	0.2	39	SAND	D	20									
SAND	D	20								48	52	0.46	1.2	12.7	32	0.25	28	SAND	D	20									
SAND	D	20	1.5-3	OUTWASH				0	0	32	68	0.46	4.6	32	76	1.4	70	SAND	D	20									
TILL	D	NO DATA																TILL	D	NO DATA									
PEAT	E	2	0.9	PEAT														PEAT	E	2									0.8
PEAT	E	3	2.4	SAND AND COBBLES	4													PEAT	E	3	47								1.7
PEAT	E	4	2.7	PEAT	5													PEAT	E	4									1.9
PEAT	E	12	0.9	SILTY														PEAT	E	12	70								
PEAT	E	14	1.5	PEAT														PEAT	E	14	114								0.8
PEAT	E	16	0.3	PEAT	2													PEAT	E	16									3.2
PEAT	E	18+21	.5-1	DISCONTINUOUS PEAT														PEAT	E	18+21									
PEAT	E	44	4	EXTENSIVE PEAT	1													PEAT	E	44	300								

TABLE D - 2 (cont'd)

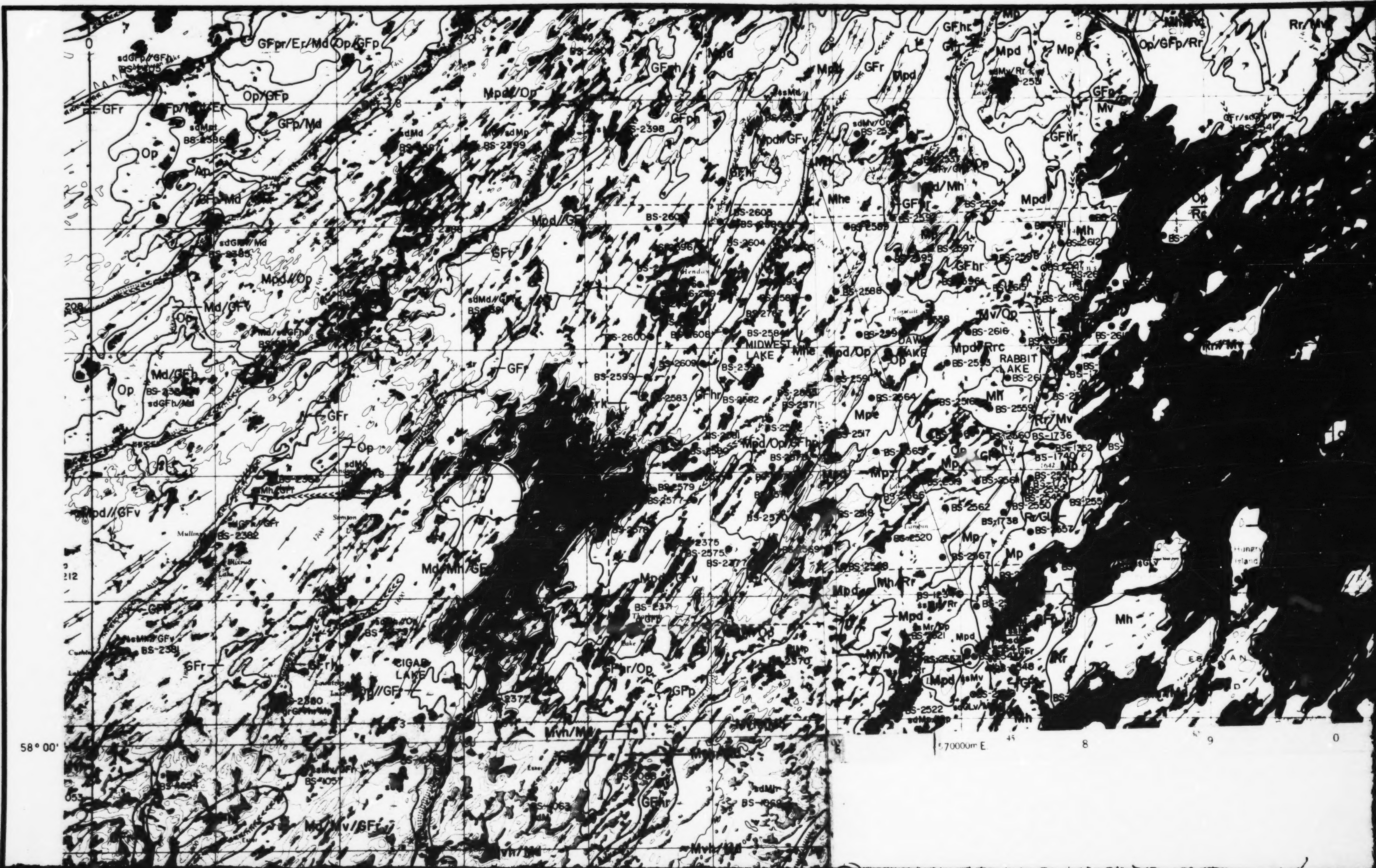
MATERIAL PROPERTIES FOR ONTARIO SITES

UNIT	AREA	REF	THICK (m)	DESCRIPTION	N	Wp %	Wl %	GRADATION (% by weight) CLAY %	SILT %	SAND %	GRAVEL %	GRAIN SIZE D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	Cc	Cu	UNIT	AREA	REF	w natural %	UNIT WEIGHT (kN/m^3)	Gs	n %	Cc	Cv (cm^2/s)	k SAT (range) (m/s)	k SAT (m/s)	D.T.W. (m)
SILT	E	3	>24	GREY C-M S INCR WITH DEPTH														SILT	E	3									1.7
SILT	E	4	0.99	GREAY CLAY AND SILT, SOFT														SILT	E	4									1.9
SILT	E	10	1.8	SILT INCR SAND WITH DEPTH														SILT	E	10									1.8
SILT	E	11	2.1	SILT COMPACT	19													SILT	E	11	27								2.3
SILT	E	15	1.5	SILT	17													SILT	E	15									2.1
SILT	E	44	1	CLAYEY SILT	10			20	78	2	0	0.0007	0.003	0.009	0.02	1	13	SILT	E	44	28								
SILT	E	44	1	SILTY CLAY	6	16	41					0.0007	0.001	0.002	0.007	0.7	3	SILT	E	44	48								
SILT	E	44	2	VARVED SILT	3	22	25											SILT	E	44	33								
SILT	E	44	3.2	SILT	8			5	87	8	0	0.004	0.01	0.04	0.06	0.6	10	SILT	E	44	25								
SAND	E	3	2.7	GREY F-C SAND, COMPACT	12													SAND	E	3	18								1.7
SAND	E	6+7	1.8	SILTY, SOME GRAVEL														SAND	E	6+7									1.7
SAND	E	11	3	F-M SAND &GRAVEL, COMPACT	17													SAND	E	11	16								2.3
SAND	E	14	3.7	MED SAND, COMPACT	13													SAND	E	14	20								0.6
SAND	E	15	6.1	SILTY F.SAND	8													SAND	E	15									2.1
SAND	E	10	3.4	F-M SAND, COMPACT														SAND	E	10									1.8
SAND	E	9	1.4	BROWN SAND GRAVEL														SAND	E	9	11								1.8
SAND	E	21+18	6	DK TAN M SSAND Hi%Mg, UPR SAND				0	2	98	0	0.2	0.4	0.6	1.5	1.3	3	SAND	E	21+18			3		36		1.0E-04		
SAND	E	21+18	5.5	LIGHT GREY V.FINE SAND				0	20	80	0	0.06	0.1	0.15	0.2	1.1	2.5	SAND	E	21+18			2.9				1.0E-05		
SAND	E	28	7.6	SAND&GRAVEL, SILT&COBBLE, V.DENS	VD													SAND	E	28							8.0E-05		
SAND	E	32	0.45	BR MED-CO SAND&GRAVEL, OVER C+B														SAND	E	32									
SAND	E	44	1.2	SILTY FINE SAND	2-16			6	40	54	0	0.008	0.05	0.1	0.2	3	13	SAND	E	44	16								
SAND	E	44	0.9	SAND AND GRAVEL	100													SAND	E	44	11								
TILL	E	1	0.9	SILTY SAND TILL, DENSE														TILL	E	1									
TILL	E	2	1.2	GREY SAND TILL, L-COMPCT														TILL	E	2									0.8
TILL	E	5	5.2	M,S+G TILL,BR-GREY, COMPACT	39													TILL	E	5									1.5
TILL	E	6+7	3.4	S+G TILL														TILL	E	6+7									1.7
TILL	E	8	1.8	M-S TILL, V.DENSE														TILL	E	8									
TILL	E	9		M-S TILL, GRAVEL&COBBLE														TILL	E	9									1.8
TILL	E	10		M-S TILL														TILL	E	10									
TILL	E	11	1.5	M-S TILL, V.DENSE	30													TILL	E	11	12								2.3
TILL	E	12	0.9	FI SA - M TILL, V.DENSE	51													TILL	E	12	21								
TILL	E	13	2.1	M-S TILL , DENSE	60													TILL	E	13									2.9
TILL	E	14	2.4	M-S TILL, V.DENSE	64													TILL	E	14	17								
TILL	E	15	9.1	M-S TILL&GRAVEL														TILL	E	15									2.1

TABLE D - 2 (cont'd)

MATERIAL PROPERTIES FOR ONTARIO SITES

UNIT	AREA	REF	THICK (m)	DESCRIPTION	N	Wp %	Wl %	GRADATION (% by weight) CLAY %	SILT %	SAND %	GRAVEL %	GRAIN SIZE D10 (mm)	D30 (mm)	D60 (mm)	D85 (mm)	Cc	Cu	UNIT	AREA	REF	w natural %	UNIT WEIGHT (kN/m^3)	Gs	n %	Cc	Cv (cm^2/s)	k SAT (range) (m/s)	k SAT (m/s)	D.T.W. (m)
TILL	E	16	1.5	SAND TILL, M+G DENSE	54													TILL	E	16									3.2
TILL	E	17	4	M-S TILL, GRAVEL&BOULDER	78													TILL	E	17									2.1
TILL	E	18	>5	SANDY TILL														TILL	E	18									
TILL	E	28	2.5	SILTY SAND TILL COBL&BLDER	126													TILL	E	28							5.0E-07		
TILL	E	31		SILTY SAND, S+C TILL, V.DENSE	VD													TILL	E	31									DRY
TILL	E	32	1.4	SILTY SAND TILL, G+C_COBBLE														TILL	E	32									
TILL	E	32	4.8	SA+GRVL TILL TO SA TILL, (AVG 8)				0	0-30	35-64	65-6							TILL	E	32							5.0E-06		.50-3.6
TILL	E	33	4.9	GRANULAR TILL														TILL	E	33		20.7					1.0E-05**	1.0E-6	.50-3.6
TILL	E	40		SILTY SAND TILL, CMP-V.DENSE	C-VD													TILL	E	40							1.0E-06	1.0E-07	
TILL	E	42	4.5	SILTY SAND TILL, OCC BLDR														TILL	E	42									
TILL	E	43	15-46	SILTY SAND TILL TR BLDR														TILL	E	43	10						1.0E-07		
TILL	E	44	1.2	SILTY SAND TILL	65			5	67-17	19-50	9-28	.004-.02	.01-.018	.035-2	.1-7	.7-.008	9-100	TILL	E	44	13								
PEAT	F	NO DATA																PEAT	F	NO DATA									
SILT	F	20	<0.3	OUTWASH				0	40	60	0	0.04	0.06	0.1	0.2	0.9	2.5	SILT	F	20									
SAND	F	20	11.3	OUTWASH				0	3-5	45-96	52-0	.5-.2	1.4-.7	9-1.3	76-2.5	.4-1.9	18-6.5	SAND	F	20									
TILL	F	NO DATA																TILL	F	NO DATA									
PEAT	G	NO DATA																PEAT	G	NO DATA									
SILT	G	NO DATA																SILT	G	NO DATA									
SAND	G	NO DATA																SAND	G	NO DATA									
TILL	G	NO DATA																TILL	G	NO DATA									
PEAT	H	NO DATA																PEAT	H	NO DATA									
SILT	H	NO DATA																SILT	H	NO DATA									
SAND	H	20	5					0	2	68	30	0.18	0.42	1.4	18	0.7	7.8	SAND	H	20									
SAND	H	20	>5					0	0	50-100	0-50	.26-0.2	.7-.3	12.7-.6	100-2	.15-.75	49-3	SAND	H	20									
TILL	H	NO DATA																											
PEAT	I	NO DATA																											
SILT	I	NO DATA																											
SAND	I	NO DATA																											
TILL	I	NO DATA																											



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sdMv/Rr
Op/GFp/Rr
Rr/Mv
GFp
Mv
GFhr
Mhe
Md/Mh
Mpd
Op
Re
Mh
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sdGFr/Md
BS-2385
Mpd/Op
Md/GFv
Op
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BS-2604
BS-2589
BS-2597
BS-2586
BS-2526
Mv/Op
BS-2616
BS-2600
MIDWEST LAKE
Mhe
Mpd/Op
DAWN LAKE
Op
Mpd/Rrc
RABBIT LAKE
BS-2593
Mh
Rr/Mv
208
Md/GFh
Op
sdGFh/Md
GFr
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BS-2609
BS-2583
GFhr
BS-2582
BS-2564
Mpe
BS-2559
BS-2517
Mpd/Op/GFhr
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Mp
BS-1736
BS-1352
BS-1740
Mp
Op
sdMp
Mh/GFr
BS-2579
BS-2577
BS-2561
BS-2562
BS-2550
BS-1738
Rr/GLr
Mpd//GFv
Mullins
BS-2382
sdGFr/GFr
BS-2570
BS-2520
BS-2575
BS-2567
Mp
Hungry Island
212
Md/Mh/GFr
Mpd/GFv
Mh/Rr
Mpd
BS-2371
GFp
GFp
BS-2381
Mpd
Mh
GFr
CIGAR LAKE
GFhr/Op
GPp
BS-2380
BS-2372
BS-2522
sdMp
BS-2521
Mvh
Rr
sdGLv
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BS-1057
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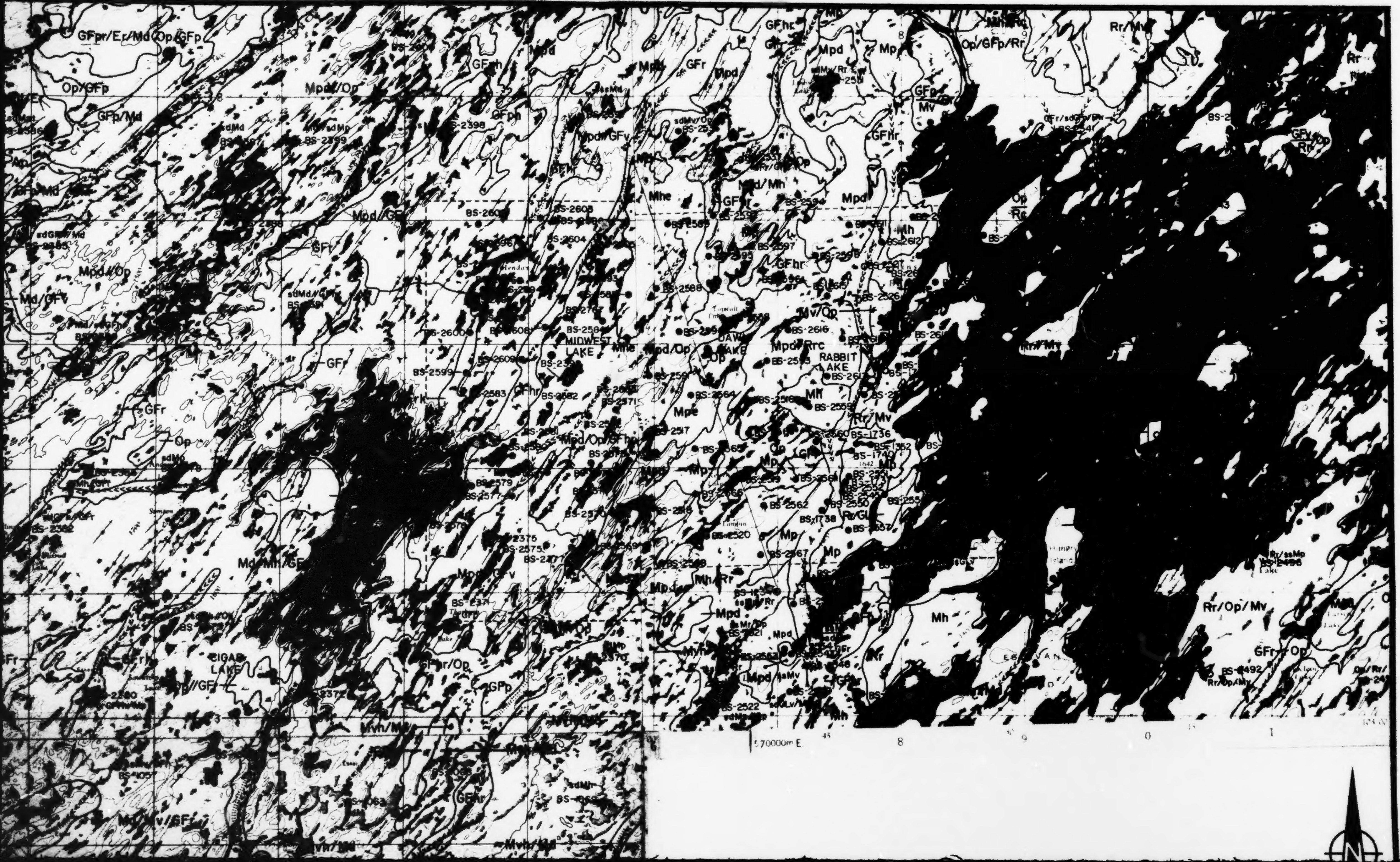
BS-1063
BS-1068
sdMh
GFhr
Md/Mv/GFr
Mvh/Md
Esker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GFph
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BS-2399
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GFhr
Mpd/GFv
Mpd/GFp
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GFr
Mpd
GFhr
Mpd
sdMv/Rr
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Op/GFp/Rr
Rr/Mv
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GFhr
Mh
BS-2612
BS-2586
BS-2616
Mv/Op
MIDWEST
LAKE
DAWN
LAKE
RABBIT
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LAKE
GFr
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GFp
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BS-2522
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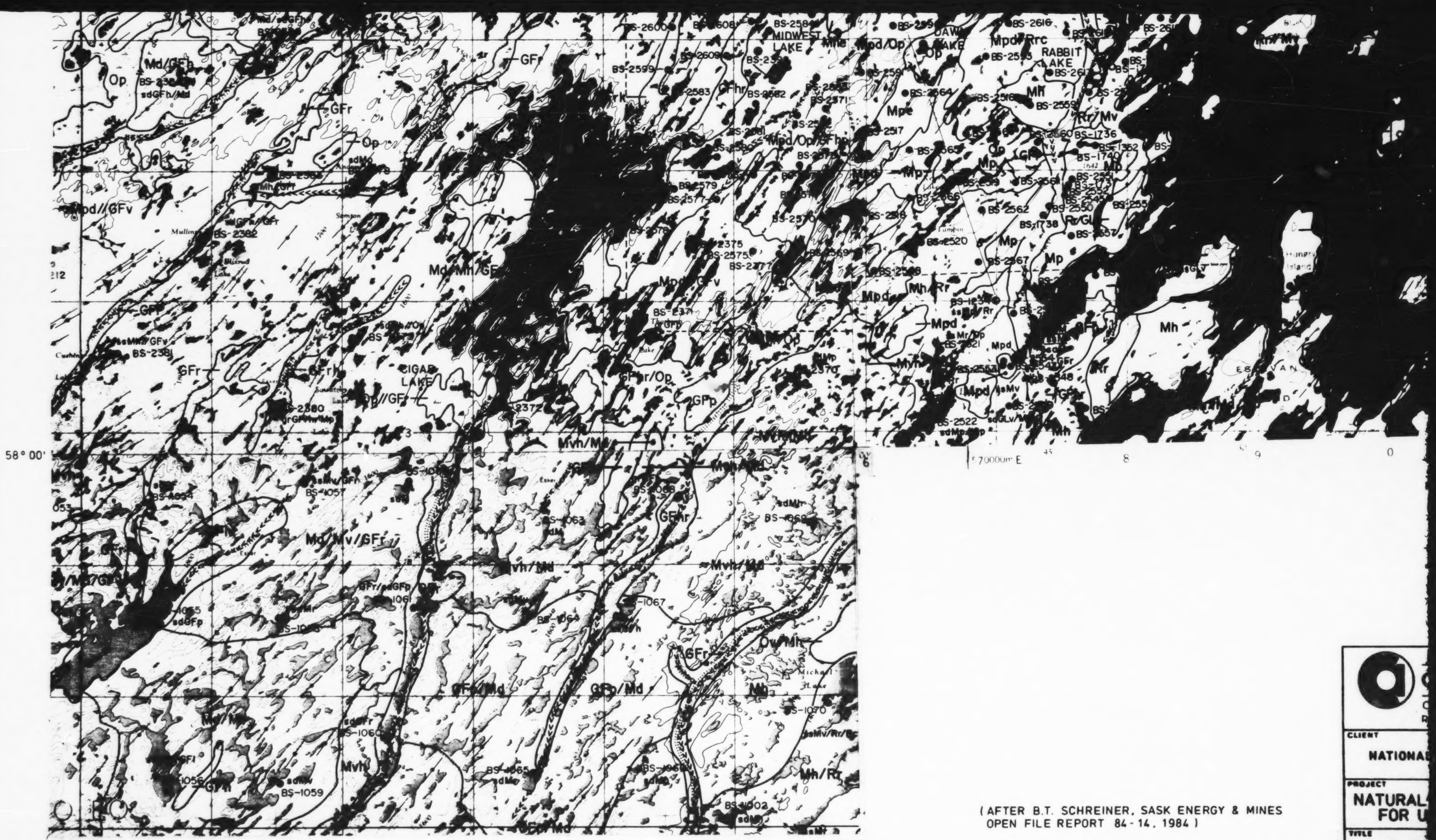

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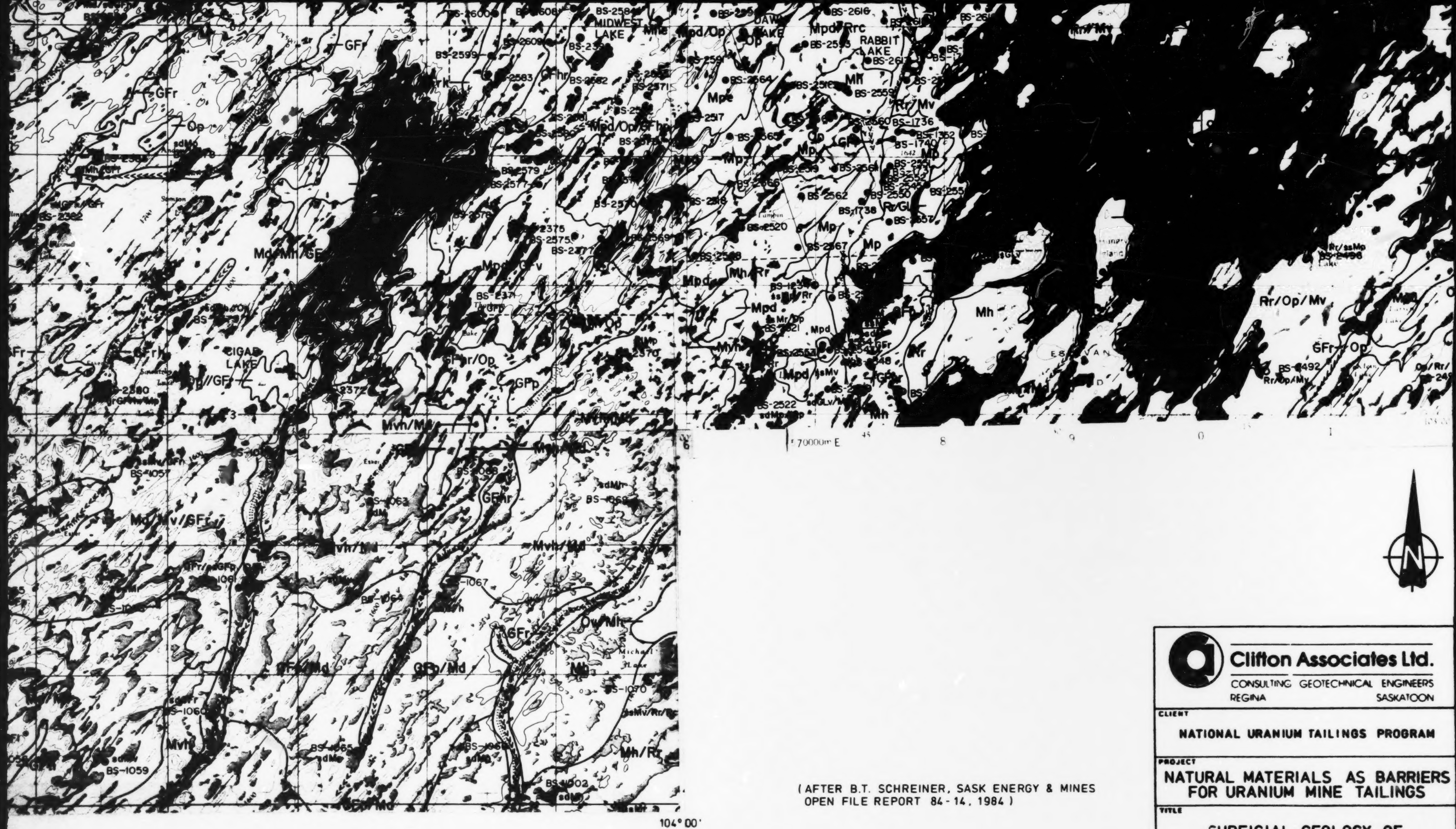

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Clifton Associates Ltd.
CONSULTING GEOTECHNICAL ENGINEERS
REGINA SASKATOON

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PROJECT	NATURAL MATERIALS AS BARRIERS FOR URANIUM MINE TAILINGS
TITLE	SURFICIAL GEOLOGY OF RABBIT LAKE-MIDWEST LAKE AREA

DATE 85/12/06	APPD BY		FIGURE C-1
SCALE AS NOTED	DWN BY J M.B		